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IN SITU SEISMIC INVESTIGATION OF COYOTE DAM

by

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An in situ seismic investigation consisting of surface refraction seismic, downhole, and crosshole tests was conducted at Coyote Dam, near Ukiah, California. Compression- and shear-wave (P- and S-wave) velocities as a function of depth were determined at two cross sections of the dam (sta 118+00 and 126+00). P- and S-wave velocity profiles were also determined for the materials which comprise the left abutment.

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20. Abstract (Continued)

The profiles constructed for the dam showed that P-wave velocities in the core increased from 2100 to 4000 fps with depth. The random fill section of the dam was determined to have a velocity of 3600 fps. A horizontal gravel blanket drain underlying the random section was determined to have a velocity of 4800 fps. The P-wave velocity of the dam's foundation materials had velocities ranging between 4100 and 7600 fps.

The S-wave velocity profiles showed that velocities in the dam's core increased from 850 to 1250 fps except at sta 126+00 where a velocity of 950 fps was noted for the lower 50 ft of core material. The random fill section of the dam had a velocity of 1400 fps, with its underlying horizontal gravel drain having a velocity of 1600 fps. The foundation materials were determined to have velocities between 1450 and 2650 fps.

The materials on the left abutment displayed P-wave velocities ranging between 1600 and 5500 fps. The S-wave velocities for these materials ranged between 850 and 1950 fps.

Preface

An in situ seismic investigation at Coyote Dam was authorized by the U. S. Army Engineer District, San Francisco, California, in IAO No. E86-79-3019, Appropriation No. 96X4902.

The field investigation was performed during the periods 12-15 May 1979 and 19 July - 8 August 1979 by Messrs. Ronald E. Wahl, Jose L. Llopis, Joseph R. Curro, Jr., Edwin S. Stewart, and Donald H. Douglas of the Field Investigations Group (FIG), Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES). The analysis phase of this study was performed by Messrs. Wahl, Llopis, and Robert F. Ballard, Jr., under the general supervision of Dr. William F. Marcuson III, Acting Chief, EEGD, and Dr. Don C. Banks, Acting Chief, GL. This report was written by Messrs. Wahl, Llopis, and Ballard.

COL John L. Cannon, CE, and COL Nelson P. Conover, CE, were Commanders and Directors of WES during the performance of this investigation and the preparation of this report. Mr. Fred R. Brown was Technical Director.

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Conversion Factors, U. S. Customary to Metric (SI)
Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

IN SITU SEISMIC INVESTIGATION OF COYOTE DAM

PART I: INTRODUCTION

Background, Purpose, and Scope of Study

1. Current seismic analysis procedures for earth dams and foundations require values of compression- and shear-wave (P- and S-wave) propagation velocities as a function of depth for program input. A suite of seismic tests are used in an in situ geophysical investigation to determine P- and S-wave velocities and velocity zones. These tests are used in conjunction with conventional field sampling and laboratory testing to provide soil property information for a dynamic analysis of the dam and its foundation under earthquake excitation.

2. To accomplish such an analysis for Coyote Dam, a geophysical investigation was conducted at the project, which is located on the East Fork of the Russian River about 3 miles* north-northeast of Ukiah, California, as shown in Figure 1. The investigation was conducted to determine P- and S-wave velocities as a function of depth within the dam and underlying foundation material.

Site Description

3. The dam is an earthfill structure with a crest length of 3500 ft, a crown width of 20 ft, and a maximum height of 170 ft (Figure 2). Its construction was completed in 1959. The dam has a central impervious core, a random fill shell, and a horizontal drain that was placed on alluvium. The "bedrock" that the dam is founded upon is the Ukiah Formation, an alluvial deposit, consisting of a well-consolidated, weakly cemented, clayey, sandy gravel with a matrix of clay, clayey sand, and sandy clay.

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* A table of factors for converting U. S. customary to metric (SI) units of measurement is presented on page 3.

Test Program

4. A preliminary geophysical test program was prepared by personnel of the U. S. Army Engineer District, San Francisco (SFD), and submitted to the U. S. Army Engineer Waterways Experiment Station (WES) for review. The final test program, as mutually agreed upon by SFD and WES, consisted of four surface refraction lines and six sets of uphole/downhole and crosshole tests. Each of these latter tests required three plastic-cased borings. Locations of these tests are shown in Figure 3.

Surface refraction seismic tests

5. Surface refraction seismic tests were conducted to obtain P-wave velocities as a function of depth from the ground surface, layering (depth to interfaces having contrasting velocities), and anomalous conditions (if any). The surface refraction seismic program consisted of 11 strategically located traverses (four lines). Location and orientation of the seismic lines, which were designated as A through D, are shown in Figure 3. Forward and reverse traverses were run in all four locations. Lines A and B were 650 and [illegible]50 ft in length, respectively, and were run along the crest of the dam. Lines C and D were 590 and 400 ft in length, respectively, and were run parallel to the longitudinal axis of the dam on the downstream toe. Line D had an additional shotpoint at the center of the line and shotpoints which were offset 100 and 170 ft from either end of the line.

Crosshole tests

6. Crosshole tests were conducted in six borehole sets, each set consisting of a pattern of three borings at locations shown in Figure 3. The purpose of the crosshole investigation was to determine horizontal P- and S-wave velocities as a function of depth.

7. One virtue of crosshole testing as opposed to surface refraction seismic testing is its ability to detect lower velocity layers underlying or sandwiched between layers of higher velocity. The former technique is therefore considered to be inherently more definitive and accurate than that of the latter, but has the shortcoming of not being able to cover as much area; hence, their complementary use.

8. Borehole set ABC was approximately 150 ft deep and was located on the crest of the dam near sta 118+00. These borings passed through the impervious core and penetrated about 50 ft of foundation material. Borehole set GHI was about 200 ft deep and was also located on the crest of the dam near sta 126+00. These borings also passed through the impervious core and penetrated about 25 ft of foundation material. Borehole set DEF was approximately 50 ft deep and located on the dam's left abutment. These borings, according to plan, penetrated the Ukiah Formation only. Borehole set PQR was located on the downstream side of the dam near sta 126+00 at el 724,* which was 60 ft below the crest of the dam. These borings were 120 ft deep passing through the random fill section of the dam, ultimately penetrating about 15 ft of foundation material. Borehole sets JKL and MNO which were located on the downstream toe of the dam near sta 126+00 and 118+00, respectively, penetrated 150 and 100 ft, respectively, of the foundation material. The three borings of each borehole set were drilled in line approximately 20 ft apart at the ground surface. Each borehole set, with the exception of set DEF (left abutment), was positioned on a line parallel to the axis of the dam.

9. All borings for the crosshole tests were drilled 8 in. in diameter and cased with 4-in. ID PVC pipe by WES personnel. The annular space between the casing and walls of the borings was grouted with a mixture of portland cement, bentonite, and water, which after setting up had a firm consistency. A borehole deviation survey was conducted by WES personnel to determine precise alignment because accurate reduction of data from the crosshole tests requires knowledge of the horizontal drift of each borehole so that the straight-line distance between boreholes at each depth tested can be established.

10. The crosshole data collected from each of the six sets were analyzed with the aid of a computer program developed at WES.**

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* Elevations (el) cited are in feet referenced to mean sea level.

** Butler, D. K., Skoglund, G. R., and Landers, G. B. 1978. "CROSSHOLE: An Interpretive Computer Code for Crosshole Seismic Test Results, Documentation and Examples," Miscellaneous Paper S-78-8, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Uphole/downhole tests

11. Jphole P-wave tests were conducted in boreholes B, E, H, and K, while a downhole P-wave test was conducted in borehole O. The purpose of these tests was to complement the surface refraction seismic and crosshole test data thereby increasing overall confidence in data obtained.

12. In addition to the determination of P- and S-wave velocities, uphole/downhole tests can be used to detect velocity inversions, i.e. low velocity layers underlying high velocity layers. However, certain limitations must be recognized:

a. Lower velocity limits are usually established by the velocity of the casing or grout (approximately 7000 ft/sec) which can act as a wave guide for the vertically traveling seismic waves; however, if the signature of a later seismic wave arrival can be identified as that of the soil traveling wave (as was the case at Coyote Dam), it is sometimes possible to determine the soil velocity.

b. Accuracy of incremental velocities is directly related to the preciseness of timing control available on the seismographic equipment. In high velocity materials, incremental time differences could be on the order of 1 or 2 msec. Therefore, an error of 0.5 msec in a distance of 10 ft or less would be appreciable. In view of the above, uphole/downhole tests must be used with discretion.

13. All phases of the test program were conducted in accordance with procedures outlined in EM 1110-1-1802.* In this manual, a detailed description of each of the test techniques mentioned above is presented along with pertinent background information.

* Headquarters, Department of the Army. 1978. "Geophysical Exploration," Engineer Manual EM 1110-1-1802.

PART II: TEST RESULTS

Surface Refraction Seismic Tests

14. Basic data acquired during the conduct of surface refraction seismic tests are conventionally displayed in a time versus distance format in Figures 4-7 for seismic lines A through D, respectively.

15. Four velocity zones were indicated from the data collected along seismic line A (Figure 4). The near-surface zone had a true velocity of about 2000 fps and extended from ground surface to depths varying from 24 to 28 ft. Zone 2 exhibited a true velocity of 2550 fps and extended from the bottom of the near-surface layer to depths varying between 54 and 65 ft. The third zone showed a true velocity of 3450 fps extending from the bottom of the second zone to depths varying between 106 and 128 ft where a fourth zone having a true velocity of 6650 fps extending to undetermined depths was encountered.

16. The time versus distance plot for seismic line B is shown in Figure 5. Three velocity zones were indicated on this plot. The near-surface zone had a true velocity of 2000 fps extending from ground surface to depths which varied between 30 and 35 ft. The second zone had a true velocity of 3100 fps and extended from the bottom of the near-surface zone to depths varying between 101 and 103 ft where the third zone having a true velocity of 4400 fps extending to undetermined depths was encountered.

17. The time-distance plot for seismic line C is presented in Figure 6. The southerly traverse of this line revealed three velocity layers, while the northern portion of the line showed only two layers. In many cases, this means that the second zone in the forward running traverse was probably "pinched out" somewhere near the center of the line and consequently was not detected by the reverse traverse.

18. The time-distance plot for seismic line D is shown in Figure 7. The multiple shotpoint configuration indicated that only two velocity zones were present. The velocities of these zones were computed by a simple numerical average of the true velocities of the

extended lines with those not extended. The near-surface zone had an average velocity of 1250 fps and extended to depths varying between 12 and 15 ft where the second zone was encountered with a true velocity of 4950 fps extending to undetermined depths.

Uphole/Downhole P-Wave Tests

19. Vertical P-wave velocities are normally obtained using the first seismic arrival time. In some instances, however, the first arrival time is influenced by casing, grout, or a combination of both. First arrivals at the Coyote site exhibited a fairly constant P-wave velocity of about 7000 fps, an obvious conflict with the surface refraction seismic. Close scrutiny of the uphole/downhole records revealed a later arriving signal which exhibited a characteristic signature easily correlatable between test points. The consistent use of this seismic event resulted in the interpretation of the true vertical soil profile velocity as presented herein.

20. Basic data acquired during the conduct of the uphole/downhole tests are conventionally presented in a time versus slant distance configuration (the slant distance is nearly equal to the depth). Figures 8-13 show vertical velocity data obtained at each of the borehole sets.

21. Figure 8 is the presentation of data acquired during the uphole P-wave tests at set ABC (boring B was the source hole used for this test). It should be noted that three straight lines can be fitted to the data thus indicating the presence of three velocity zones as tabulated:

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	2150
2	15	3150
3	111	6650

22. The time-distance plot for the uphole P-wave test run at boring E of borehole set DEF on the left abutment is shown in Figure 9.

In this case, only five data points were obtained which will affect overall reliability of the interpretation. Again, three straight-line segments were used to fit the data, consequently, depicting three velocity zones as follows:

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	1450
2	8	3000
3	24	5900

23. The time-distance plot for the uphole P-wave test conducted at boring H of the set GHI is presented in Figure 10. Three velocity zones were determined from three slopes used to fit 21 data points as follows:

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	1950
2	34	4100
3	174	6950

24. The time-distance plot for the uphole P-wave test conducted at boring K of the set JKL is presented in Figure 11. Four velocity zones were determined in this test. Note that zone 2 averaged a 50 percent higher velocity than zone 3. This finding was substantiated by crosshole tests which will be discussed later. The following is a tabulation of uphole data obtained at boring K.

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	1400
2	12	6000
3	42	4200
4	96	6850

25. The time-distance plot for the downhole P-wave test conducted at boring O of set MNO is presented in Figure 12. The source was located on the surface 5 ft south of hole O, with the receiver geophone placed in hole O. Only two velocity zones were determined using the ten data points shown in Figure 12:

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	1400
2	11	7950

26. The time-distance plot for the uphole P-wave test run at boring Q of set PQR is presented in Figure 13. Using three slopes to fit 12 data points, three velocity zones were determined as follows:

Zone	Depth to Top of Interface, ft	Velocity, fps
1	0	1650
2	10	3450
3	88	6600

Crosshole Tests

27. The calculated true P- and S-wave velocities as determined by the crosshole computer program for all six crosshole sets at Coyote Dam are presented in Figures 14-16 which show P- and S-wave velocities at all test elevations for each crosshole set. Figure 14 shows the calculated true velocities determined by the crosshole method through the cross section of the dam at sta 118+00, which includes crosshole set ABC (crest) and set MNO (downstream toe). Figure 15 shows the calculated true velocities through the cross section at sta 126+00 from three crosshole sets including set GHI (crest), set PQR (midslope on downstream side), and set JKL (downstream toe). Figure 16 shows the calculated true velocities obtained from crosshole set DEF on the right abutment.

Data Consolidation

28. In order to present a meaningful interpretation of the data acquired at various points along the dam using three separate geophysical techniques, it is often convenient to present the data in composite form so that a zonal interpretation can be developed using all the data at hand. These data composites are presented in Figures 17-19.

29. Figure 17 is the P-wave composite of a cross section through sta 118+00. Note that both on the dam crest and the downstream toe, vertical velocity data from uphole/downhole tests, crosshole, and surface refraction data are presented. Considering that the three methods are designed to complement one another and each has limitations and virtues, the numbers are thought to be in reasonably good agreement.

29. Figure 18 shows the P-wave composite for the cross section through sta 126+00. Uphole, crosshole, and surface refraction data are presented for both the crest and downstream toe. The data presented at the dam midsection show only results of uphole and crosshole because surface refraction was not run in this vicinity. It is felt that the data agreement between test methods is reasonable. One point worthy of note, however, is the fact that a somewhat lower velocity zone exists on the downstream toe at sta 126+00 when compared with the downstream area of sta 118+00. It is felt that this also is reasonable in view of the fact that the old river channel probably existed in the area of sta 126+00 and the material deposited in the two locations may be somewhat different.

30. Figure 19 is a composite presentation of P-wave data obtained at the left abutment. Only crosshole and uphole data could be used for this presentation. No surface refraction seismic test was conducted at this point. Excellent agreement exists between the uphole and crosshole data. Near-surface P-wave velocities vary between 1450 and 1700 fps. The midstratum varies between 2500 and 3000 fps, and materials below a depth of about 25 ft fluctuate between 5000 and 5900 fps.

PART III: INTERPRETATION

P-Wave Velocities

31. A P-wave zonal velocity interpretation was derived using arithmetic averaging coupled with engineering judgment with regard to overall data quality. Two approaches were used as a means of presenting data for use in the finite element grid which is normally constructed for the seismic wave propagation. The first, and more detailed approach, is presented in Figures 20-22.

32. Figure 20 presents data acquired at boring sets ABC and MNO at sta 118+00. Borings ABC on the crest of the dam yielded the following P-wave velocity profile. From surface to a depth of about 18 ft, an average of 2100 fps was established. At this point, extending to a depth of about 55 ft a velocity zone of 2700 fps was determined. From a depth of 55 ft to about 118 ft, a zone whose velocity was 3600 fps, was present, whereupon, the Ukiah Formation was encountered and to a depth of 150 ft the velocity was found to average 7900 fps. The boring log for hole A in the boring set ABC showed that the dam's core extended from the surface to a depth of slightly more than 100 ft at which point a gravel drain was encountered overlying the top of the Ukiah Formation. On the downstream toe, boring set MNO at el 675 showed that from ground surface to a depth of approximately 15 ft, the overburden material exhibited a P-wave velocity of about 2000 fps. From a depth of 15 to 100 ft, the Ukiah Formation exhibited 7400 fps.

33. Figure 21 shows the P-wave velocity interpretation through a section at sta 126+00. On the crest of the dam, borings GHI were used to establish a P-wave zone of 2050 fps to a depth of about 35 ft. At this point, extending to a depth of about 170 ft, a velocity of 4000 fps was established. The Ukiah Formation was encountered at about 170 ft, and a velocity of 7000 fps was then determined. Borings PQR midway downslope at el 715 ft revealed a P-wave velocity of 2300 fps in the near-surface material to a depth of 15 ft thereupon encountering a higher velocity zone of 3600 fps extending to a depth of 85 ft. From 85 ft to

a depth of 100 ft, 4550 fps was interpreted. The gravel drain overlying the Ukiah Formation exhibited a P-wave velocity of about 3950 fps, whereupon 6800 fps was detected at the top of the Ukiah Formation.

34. At the downstream toe (boring JKL), at el 630, the overburden material exhibited a velocity of 1350 fps to a depth of 13 ft, where a gravel layer extending from 13 to 20 ft was encountered with a velocity of 5550 fps. According to the information contained in the driller's log, at boring I, the Ukiah Formation was identified at a depth of 20 ft. P-wave velocities measured from 20 ft to a depth of 106 ft averaged only 4100 fps. This was in sharp contrast to the 7000+ fps measured at other locations where the Ukiah Formation had been tested. One possible explanation for this decrease in velocity could be attributed to the manner in which materials were deposited by the old river whose channel is thought to lie in the general vicinity of borings JKL. Shale was identified at a depth about 120 ft in boring I, and at a depth of about 106 ft velocities increased markedly to 7200 fps and continued for the remainder of tests to a depth of 150 ft.

35. Figure 22 shows both P- and S-wave velocities determined for a section at the left abutment. Average P-wave velocities through the overburden to a depth of about 10 ft were 1600 fps. At a depth of 10 ft, which roughly coincides with the top of a gravel layer encountered in boring E, the velocity increased to 2750 fps. This continues to a depth of approximately 27 ft. Comparing this depth with the profile of hole E, one sees that the top of the weathered Ukiah was encountered at a depth of approximately 30 ft. P-wave velocity in this zone to a depth of about 40 ft was 5500 fps.

36. A second way of presenting the P-wave velocity zoning would be to collectively categorize the velocities obtained in certain constructed zones of the dam. Using the typical cross section of Coyote Dam supplied by SFD for sta 113+00 to 124+00, the WES tests at sta 118+00 were superimposed in Figure 23. Since data were taken only at two discrete points (on the crest at crosshole set ABC and the downstream toe at set MNO), the statistical population will, admittedly, be sparse. Data consistency does, however, suggest that this approach would be valid.

37. Beginning with the Ukiah Formation foundation material, an average P-wave velocity of 7600 fps was assigned. The lower half of the core material, zone C, was assigned a velocity of 3600 fps to the dashed line, thereupon a velocity of 2700 fps was assigned for the remainder of zone C until zone D was encountered at the near surface. Zone D exhibited an average of 2100 fps. No testing was done in zone B at sta 118+00, but using the data acquired at sta 126+00, a velocity of 3600 fps was assigned to this zone. The blanket drain was also assigned a velocity based upon data obtained from sta 126+00. This velocity was about 4800 fps which may not be indicative of 100 percent saturation in a granular material.

38. Taking into account that the pool elevation was 748 ft at the time the tests were conducted, the upstream portion of the dam may almost be a mirror image assuming the upstream and downstream shell are constructed of similar material. As a result, a 3600 fps was assigned to the upper half of zone B and 4800 fps assigned to that portion below the estimated phreatic surface in zone B. Since zone A was not tested, no velocity can be reliably assigned to that area.

39. Figure 24 is a similar presentation for sta 126+00. Due to the possible existence of an old channel underlying a part of sta 126+00, the velocities were affected on the downstream toe and underneath the main portion of the dam compared with sta 118+00. At sta JKL, the weathered Ukiah Formation exhibited a velocity of about 4100 fps, changing to a high of 7000 fps moving underneath the dam toward the upstream side. The blanket drain averaged 4800 fps and zone B 3600 fps. Zone C at sta 126+00 averaged 4000 fps over the entire core. Zone D was 2100 fps and zone B on the upstream side was assigned 4800 fps below the estimated phreatic surface and 3600 above. Zone A, of course, was not tested at this or any other location.

S-Wave Velocities

40. An S-wave zonal velocity interpretation can be made two ways in the same manner as the P-wave velocity interpretation discussed above.

The more detailed method is shown in Figure 25 for sta 118+00. On the crest of the dam an average S-wave velocity of 900 fps was encountered to a depth of about 35 ft, thereupon increasing to 1250 fps to a depth of nearly 60 ft, then slightly decreasing to 1100 fps at about 95 ft. At this point, 1300-fps material was encountered to the top of the gravel drain, at which time 1550 fps was recorded. Beginning at the top of the Ukiah Formation, which was approximately at the base of the gravel drain, 2100 fps was recorded to a depth of about 135 ft, then increased to 2550 fps for the remainder of the tests which were concluded at a depth of about 150 ft. At the downstream toe, the overburden material exhibited 750 fps to a depth of about 10 ft, then increased to 1900 fps at the top of the Ukiah Formation, progressively increasing to 2300 fps, then 2650 fps.

41. Observing Figure 26, which is the cross section at sta 126+00, it will be seen that S-wave velocities determined on the dam's crest to a depth of about 10 ft were 650 fps. At that point, velocity increased to about 950 fps to a depth slightly greater than 30 ft. Material having an S-wave velocity of 1250 fps was encountered from 30+ to 120+ ft. It is important to note that, at this point, which is the lower portion of the core, the velocity decreased to 950 fps. The gravel drain exhibited 1450-fps velocity, the top of the Ukiah Formation 1900 fps, and a shale-type material exhibited 1400 fps for the remainder of the tests.

42. Midway down the slope at el 715 ft, tests were conducted in the random fill material. Near-surface shear-wave velocity was 1250 fps for about 10 ft, where 1550-fps material from 10 ft to a depth of 50 ft was encountered. For the next 15 ft a 1300-fps zone was detected. From a depth of 65 to 100 ft, 1650-fps velocities were measured. The gravel drain exhibited 1850-fps velocity, and the top of the Ukiah Formation which began at the base of the gravel drain, was 2150 fps.

43. The downstream toe overburden material exhibited 600-fps shear-wave velocity increasing to 1050 fps in the gravel to a depth of about 20 ft. From the 20- to 30-ft depth, a loose soft sand was encountered which exhibited a lower velocity of 900 fps. Unlike the

P-wave velocity profile at this point, the shear-wave velocity was 2000 fps, which compared quite favorably with the tests run midway upslope and on the crest of the dam. Shale, which was encountered at a depth of 115 to 132 ft, showed a slightly decreased velocity of 1450 fps. At the depth of 132 ft, the Ukiah Formation was again encountered and exhibited a velocity of 2000 fps.

44. Figure 22 presents the S-wave velocities side by side with the P-wave zoning, both of which were representative of a cross section at the left abutment. Average S-wave velocities from ground surface to a depth of nearly 30 ft averaged 850 fps, thereupon increasing 1700 fps to a depth of about 37 ft, then decreasing to 1500 fps to a depth of 44 ft and slightly increasing at the point where the unweathered Ukiah Formation is encountered exhibiting a velocity of 1950 fps.

45. A second method of data presentation using typical cross sections supplied by SFD showed the zoning in more general terms. Zonal velocities shown in Figure 27 were the result of data averages obtained throughout the test site. The lower foundation materials (el 610 to 575 ft) exhibited a shear-wave velocity of 2650 fps as determined at crosshole set MNO and could probably be correlated to the unweathered Ukiah Formation. Shear-wave velocity slightly decreased from el 610 to 645 to 2400 fps and slightly decreased again from el 645 to 665 to about 2000 fps. These slight velocity reductions were likely attributable to varying states of effective stress, change in material composition, and/or weathering. The dam core, which was represented as zone C, exhibited an average of 1250-fps S-wave velocity. Zone D, the near-surface materials above the core, showed a velocity of 850 fps. Zone B, representative of the dam's shell, was assigned a velocity of 1400 fps based upon data obtained at sta 126+00. Zone A was, of course, not tested and zone B on the upstream portion of the dam was assigned velocities based upon material properties of the downstream side.

46. Figure 28 is representative of the zonal velocities at sta 126+00. Foundation materials were slightly lower in velocity at sta 126+00, probably because of the possible presence of the old river channel in that area. The Ukiah Formation exhibited about 2000 fps but

is interrupted midway by a layer of shale material having a velocity of 1450 fps. The lower portion of zone C, which was the core material, had a velocity of 950 fps which was lower than that above the probable water table. The upper portion of the core exhibited a velocity of 1250 fps. Zone D, the near-surface material overlying the core had a velocity of 850 fps. Zone B, on the downstream side, exhibited a velocity of 1400 fps, representative of the shell materials as tested at crosshole set PQR. Upstream velocities in zone B were assigned on the basis of the downstream. Zone A was not tested. Since no "typical" cross section of the dam's right abutment was available, no generalized zoning was attempted at that station.

PART IV: CONCLUSIONS

47. The following conclusions were drawn from the testing of Coyote Dam at sta 118+00, 126+00, and the left abutment:

Sta 118+00

a. The interpretation of P-wave data at sta 118+00 of materials which make up the core, gravel drain, and foundation shows four P-wave velocity zones. They are: 2100, 2700, 3600, and 7900 fps. The first three zones represent the core, gravel drain, and the upper portion of the foundation. The fourth zone represents the Ukiah Formation in the foundation.

b. The P-wave interpretation of materials in the downstream toe shows two velocity zones. They are 2000 and 7400 fps and represent the overburden materials and Ukiah Formation which are present in this area.

c. The S-wave interpretation of materials comprising the core, gravel drain, and foundation materials is zoned into seven layers. They are 900, 1250, 1100, 1300, 1550, 2100, and 2550 fps. The first four are the significant zones in the core materials. The fifth represents the gravel drain. The last two velocity zones represent the materials present in the Ukiah Formation underlying the dam.

d. The S-wave interpretation of the downstream toe materials at sta 118+00 indicated four S-wave zones. The upper zone has an S-wave velocity of 750 fps and represents overburden materials. The underlying Ukiah Formation is represented by three velocity zones of 1900 2300, and 2650 fps.

Sta 126+00

a. The P-wave interpretation of data collected at sta 126+00 divides the core into two velocity zones of 2050 and 4000 fps. The underlying Ukiah Formation has a P-wave velocity of 7000 fps.

b. The random fill section at sta 126+00 is made up of three velocity zones of 2300, 3600, and 4500 fps. Its underlying gravel drain has a P-wave velocity of 3950 fps. The Ukiah Formation in this area has a P-wave velocity of 6800 fps.

c. Four P-wave velocity zones were determined for the materials in the downstream toe. They are 1350, 5550, 4100, and 7200 fps. These zones represent overburden, gravel, Ukiah Formation, and shale layers, respectively.

d. The S-wave velocities for materials comprising the core indicate four S-wave velocity zones of 650, 950, 1250, and 950 fps. The underlying gravel drain has an S-wave velocity of 1450 fps. The foundation material has two zones, 1900 and 1450 fps, which represent the Ukiah Formation and underlying layer of shale, respectively.

e. The random fill materials of sta 126+00 are represented by four zones of 1250, 1550, 1300, and 1650 fps. They are underlain by a zone of 1850 fps which represents the gravel drain. The foundation materials (Ukiah Formation) are characterized by one zone with a velocity of 2150 fps.

f. Six velocity zones were determined for the downstream toe materials of sta 126+00. They are 600, 1050, <900, 2000, 1450, and 2000 fps. The first two present overburden and gravel layers. The <900-fps zone represents a loose, soft sand layer present between borings K and L. The last three values represent two sections of Ukiah Formation and a shale.

Left Abutment

a. The P-wave interpretation at the left abutment is composed of three zones of 1600, 2750, and 5500 fps. The first two zones represent overburden and gravel layers present in this vicinity. The last represents the P-wave velocity of weathered Ukiah Formation.

b. The S-wave interpretation reveals four velocity zones on the left abutment. They are 850, 1700, 1500, and 1950 fps, respectively. Loosely applied, the first zone represents overburden materials, the second two represent weathered Ukiah Formation, and the third represents the unweathered Ukiah Formation.

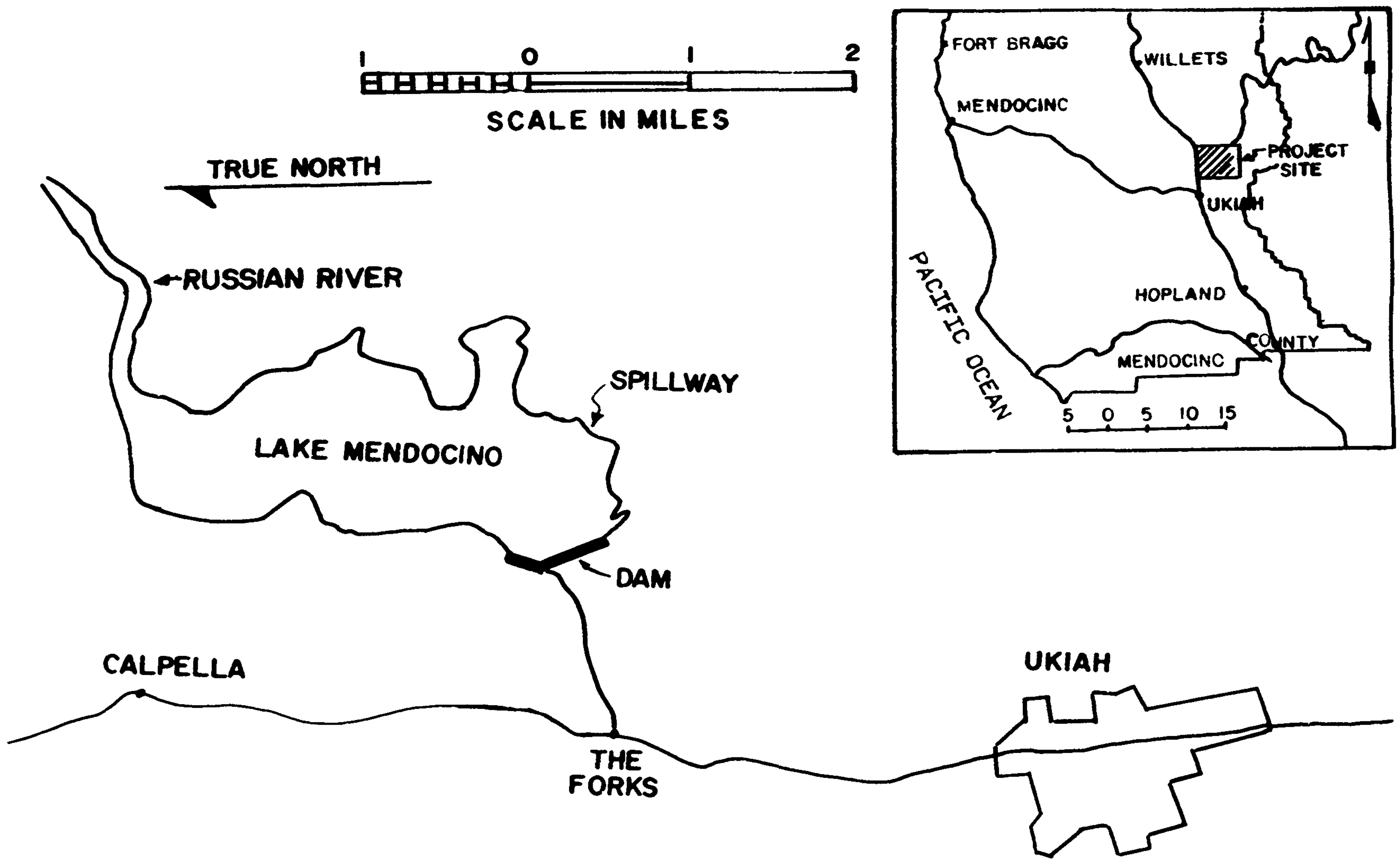


Figure 1. Locality map

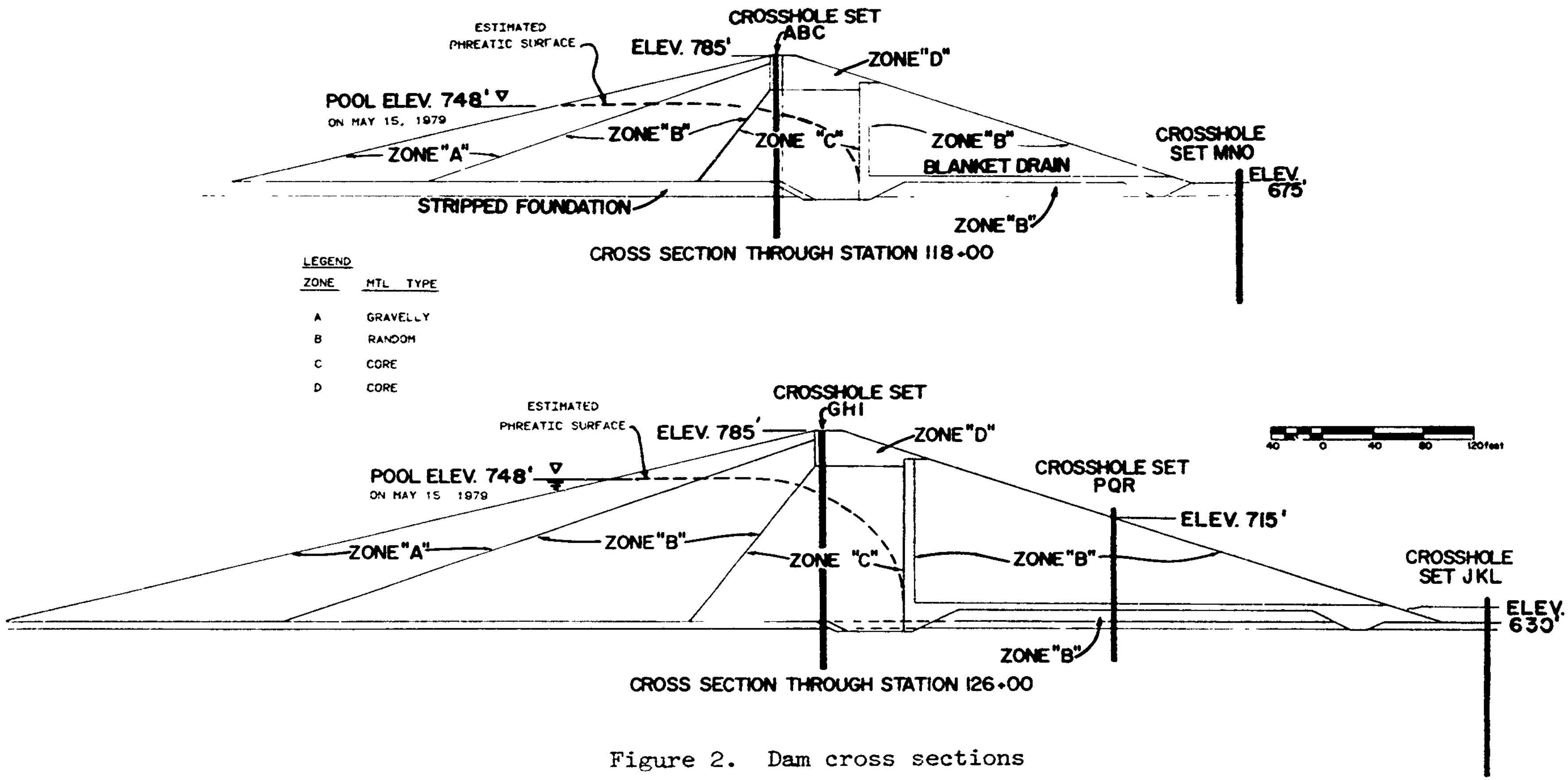


Figure 2. Dam cross sections

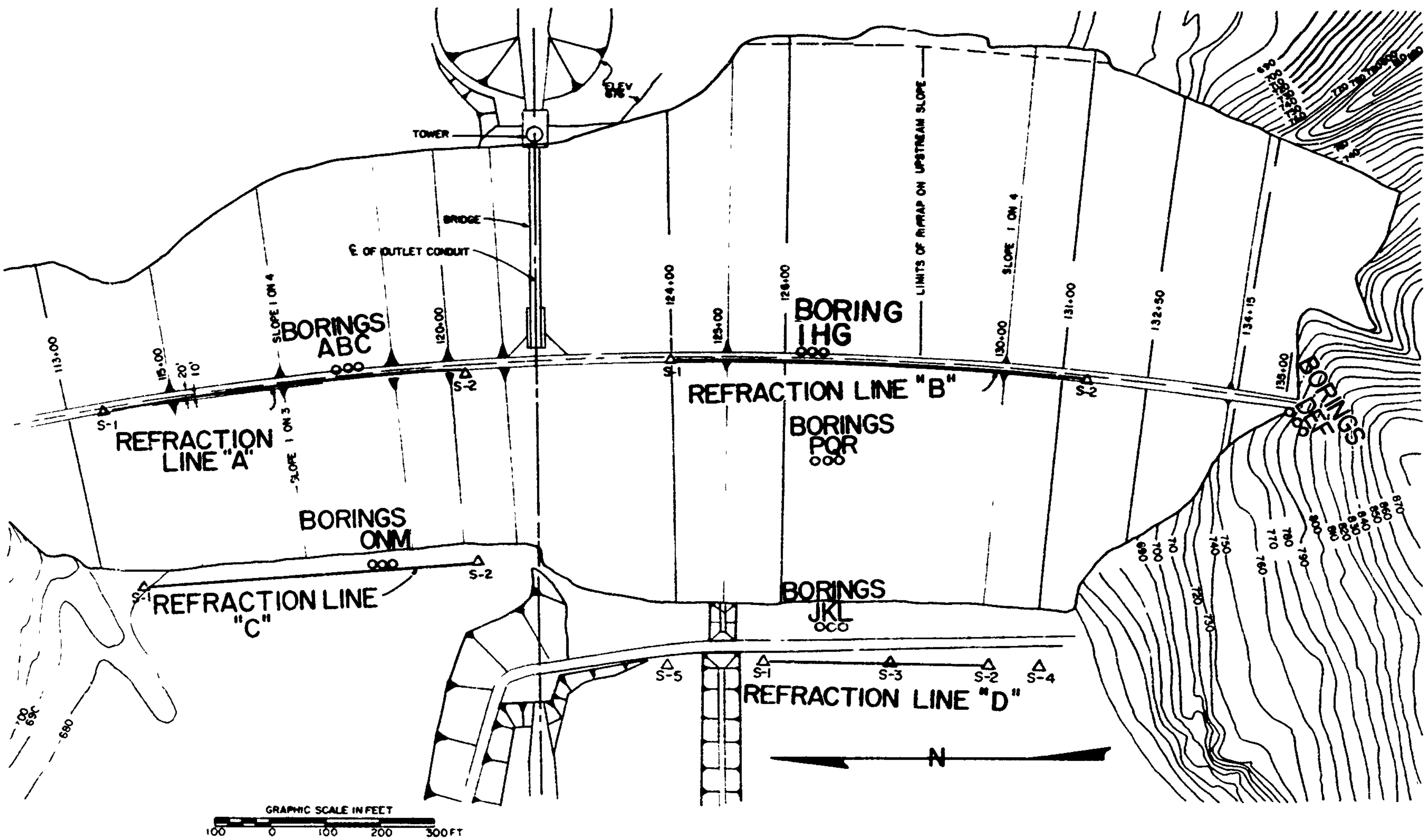


Figure 3. Plan view of Coyote Dam

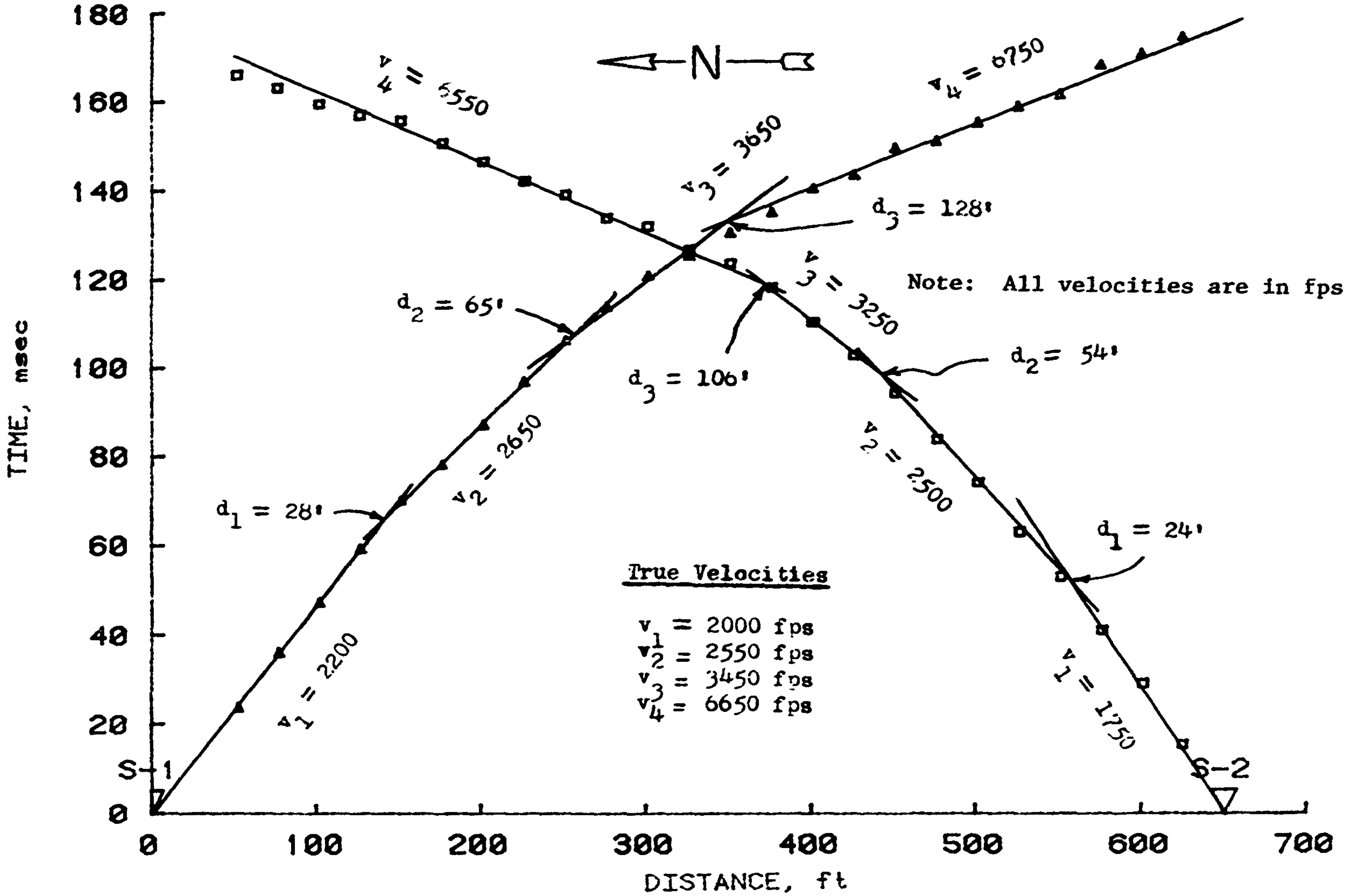


Figure 4. Surface refraction line A

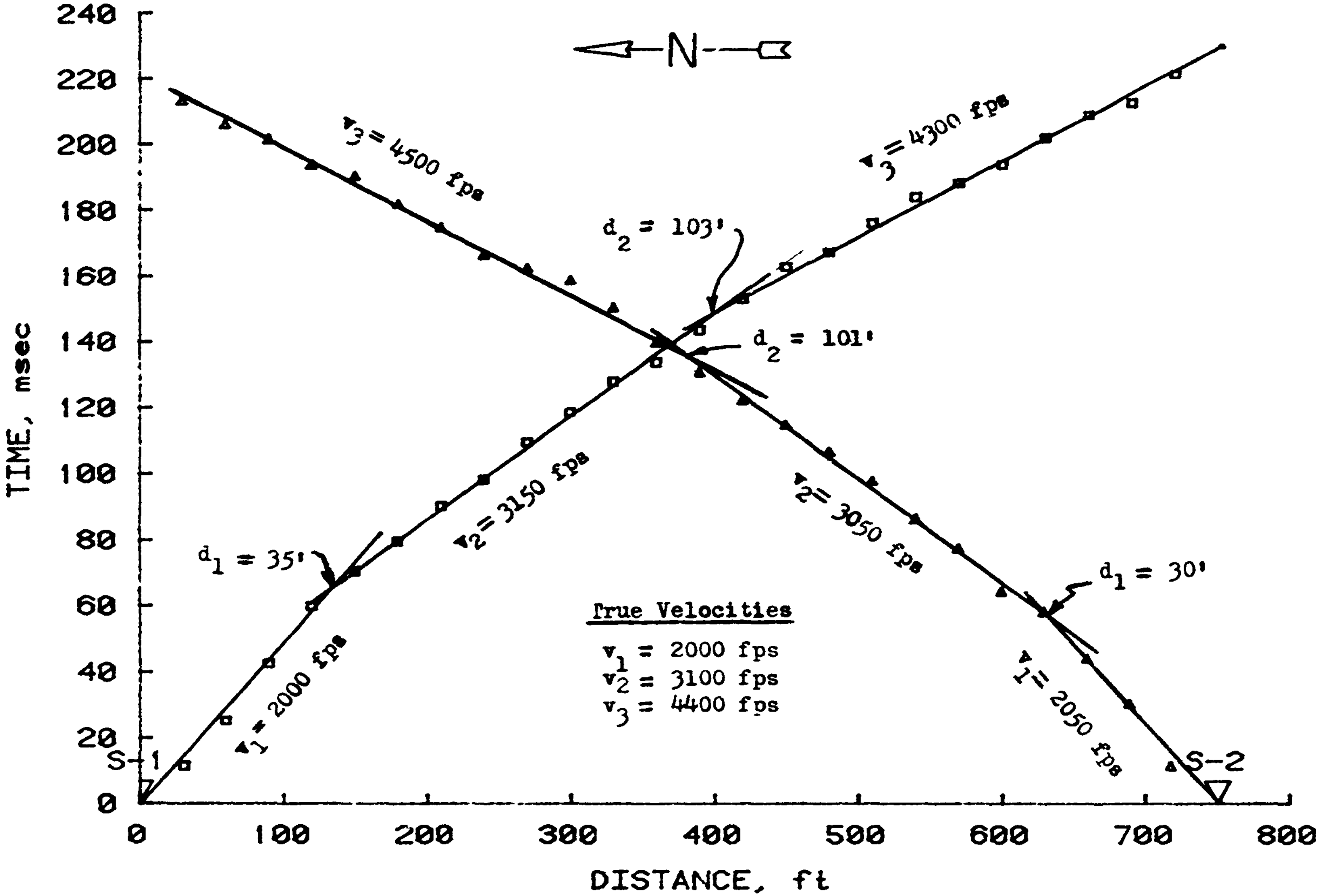


Figure 5. Surface refraction line B

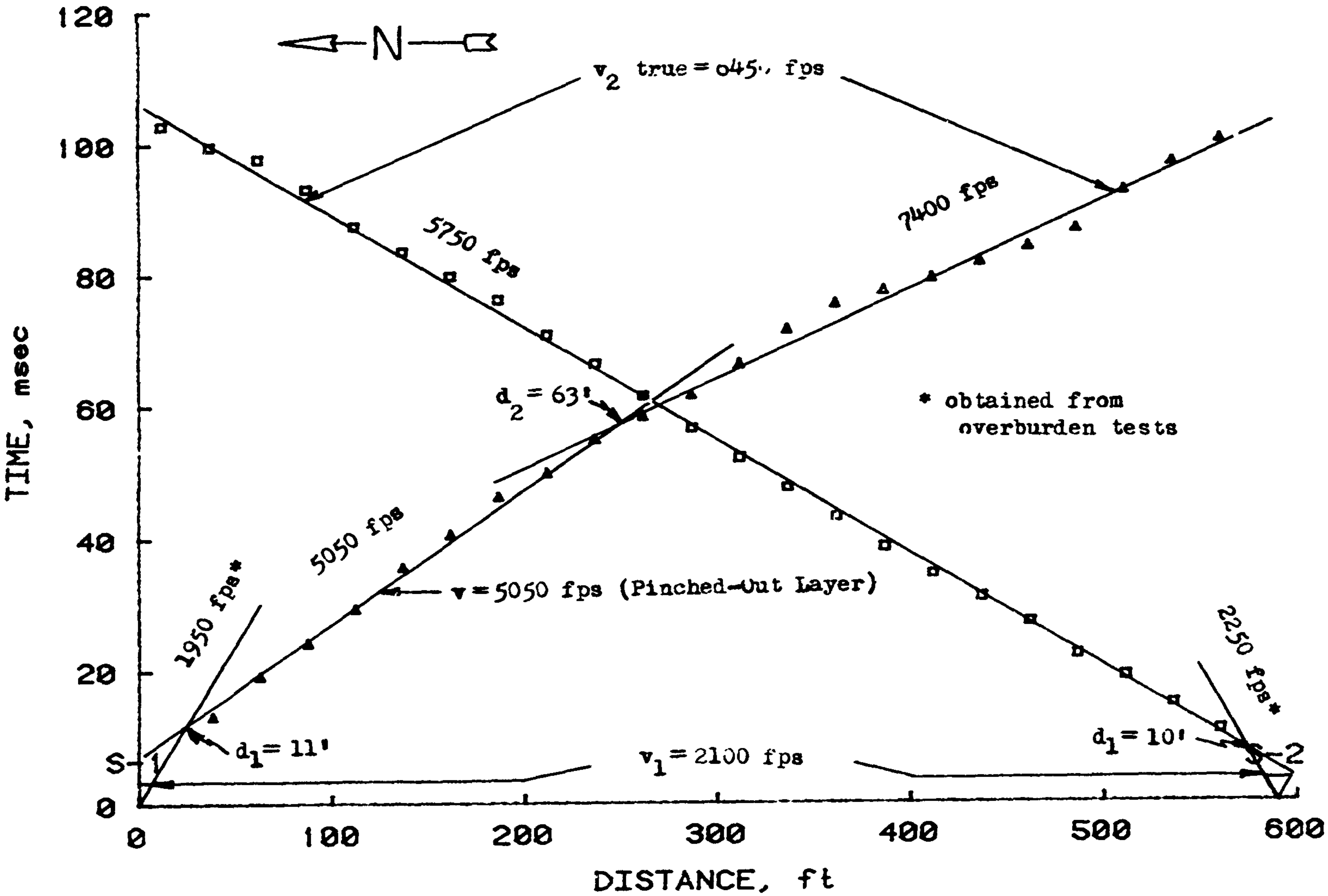


Figure 6. Surface refraction line C

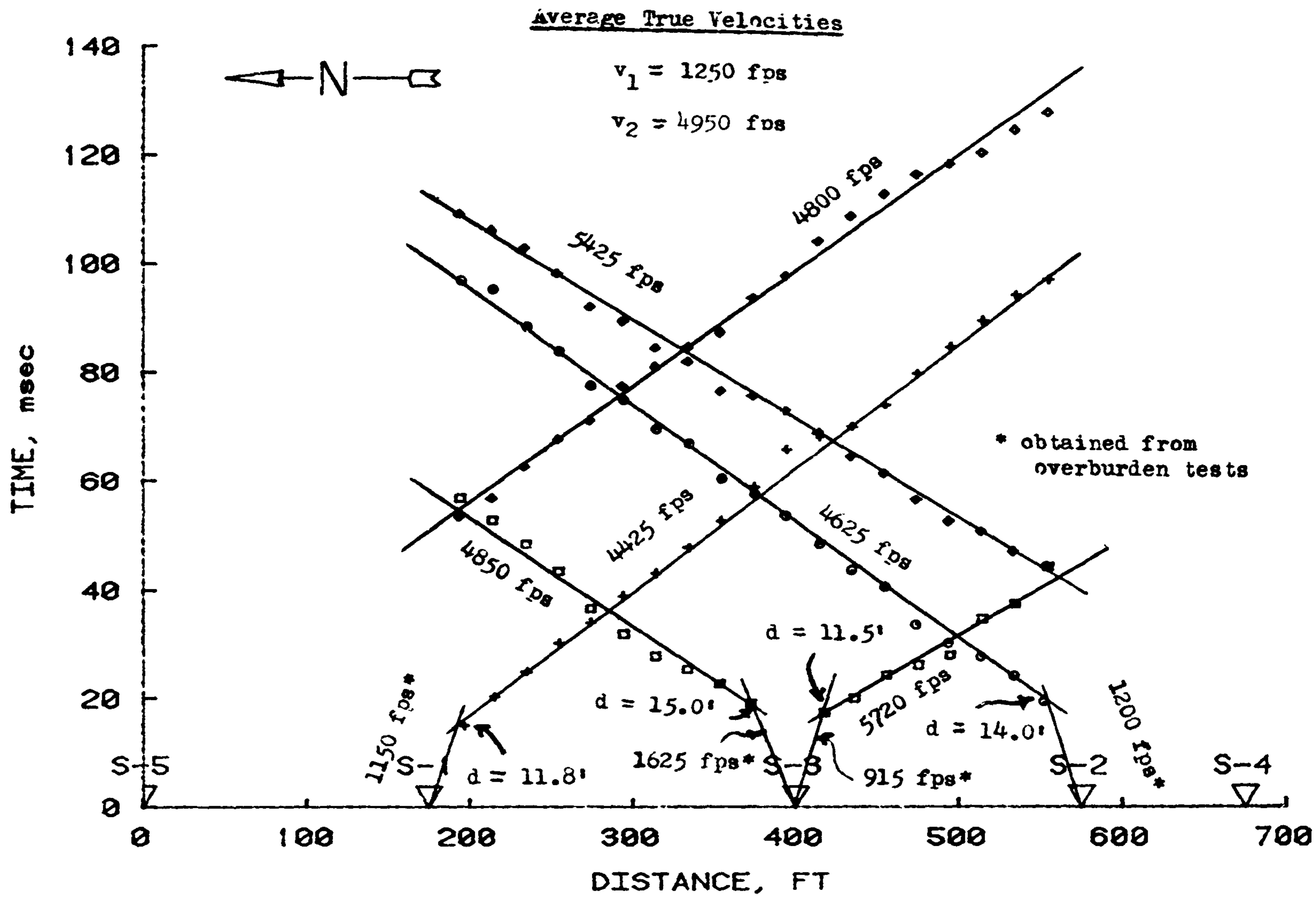


Figure 7. Surface refraction line D

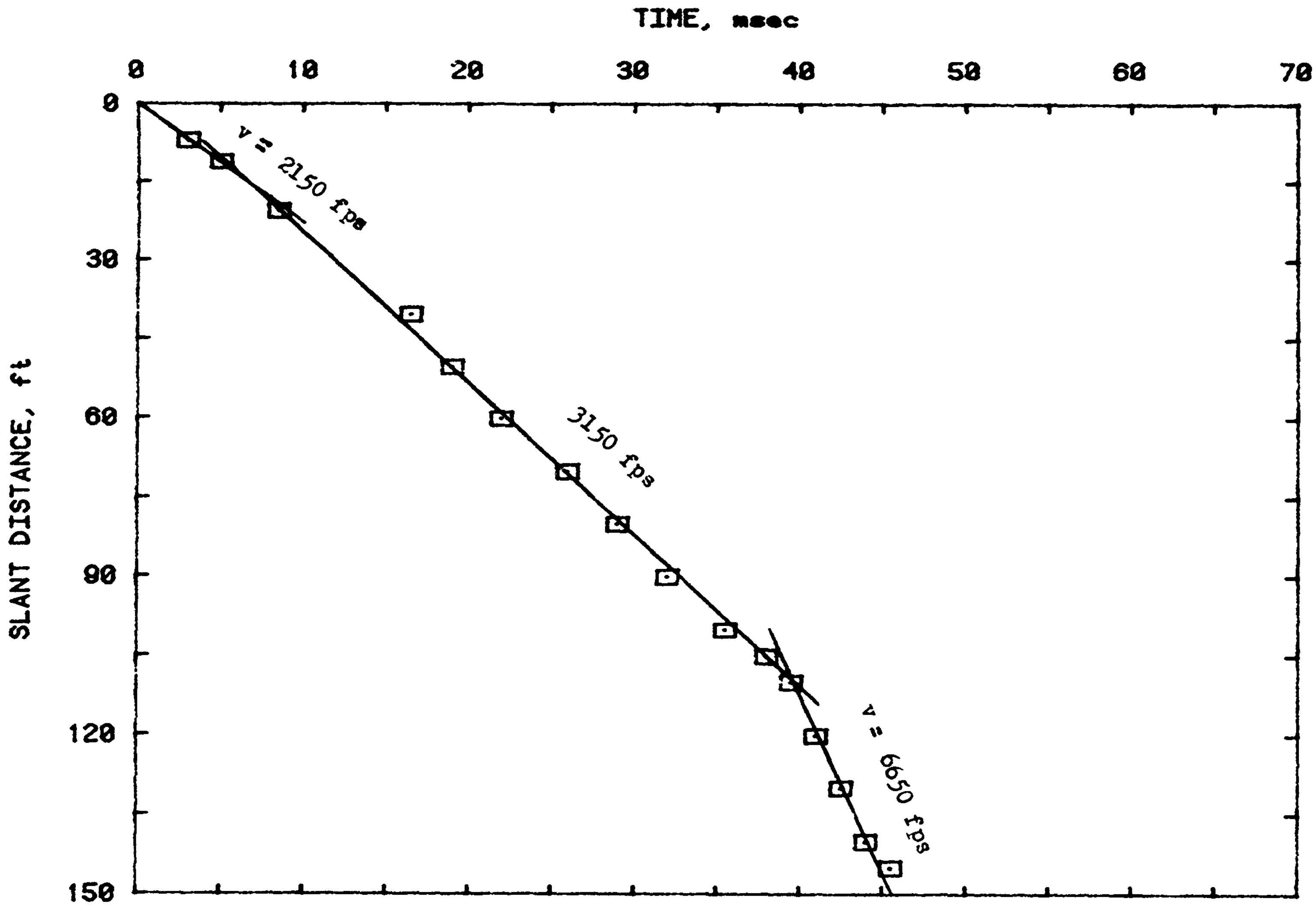


Figure 8. Uphole P-wave test conducted in borehole B

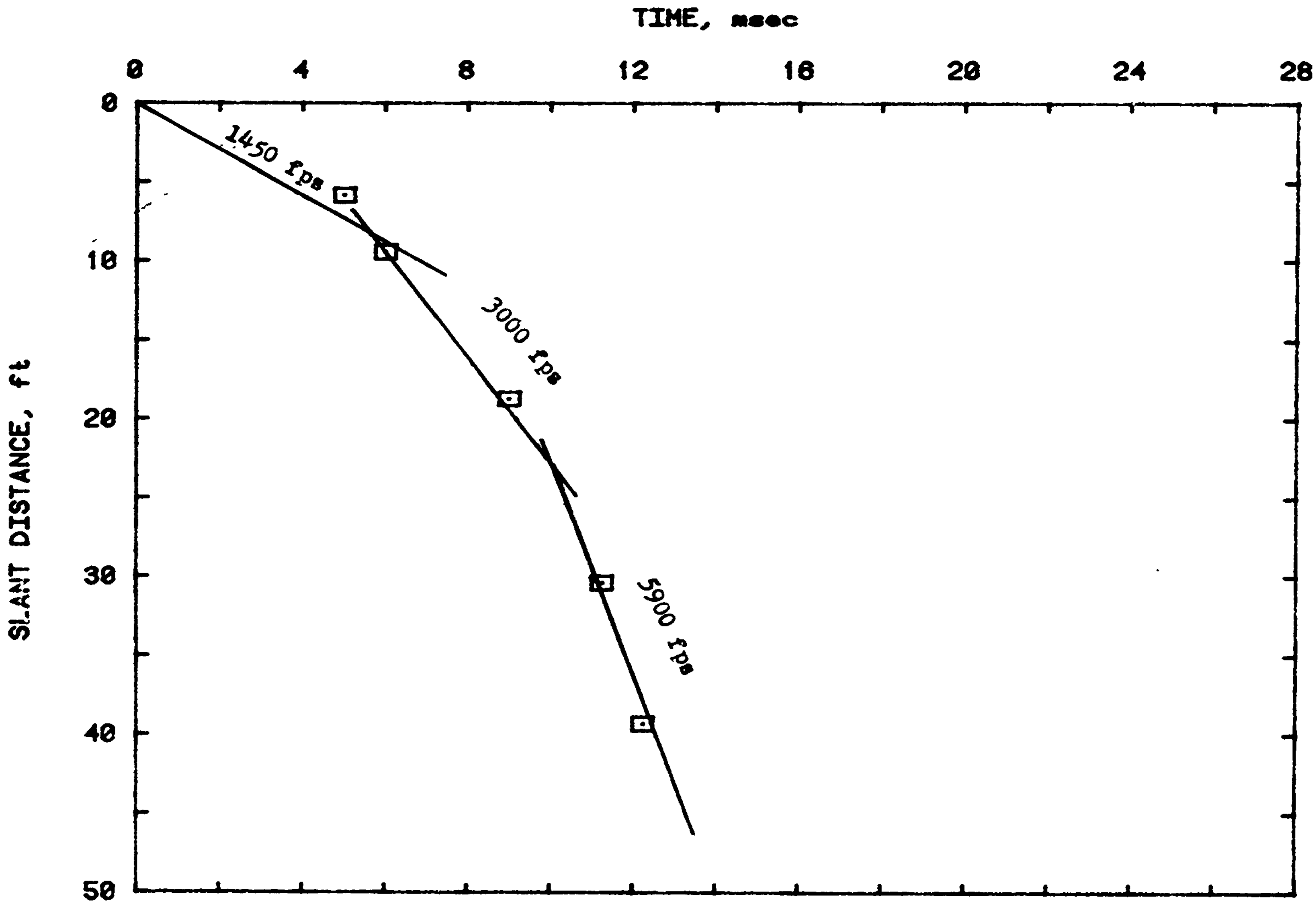


Figure 9. Uphole P-wave test conducted in borehole E

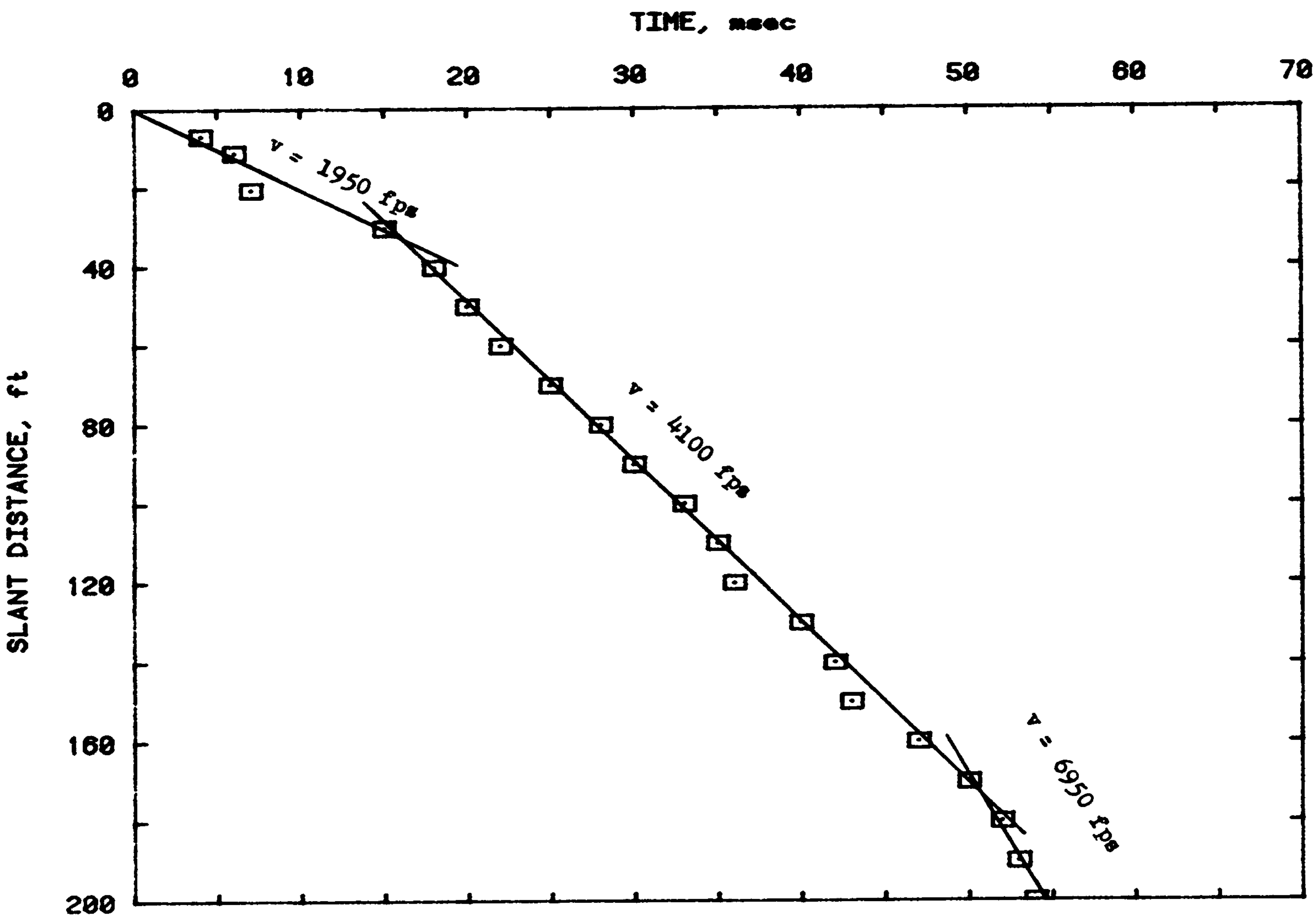


Figure 10. Uphole P-wave test conducted in borehole H

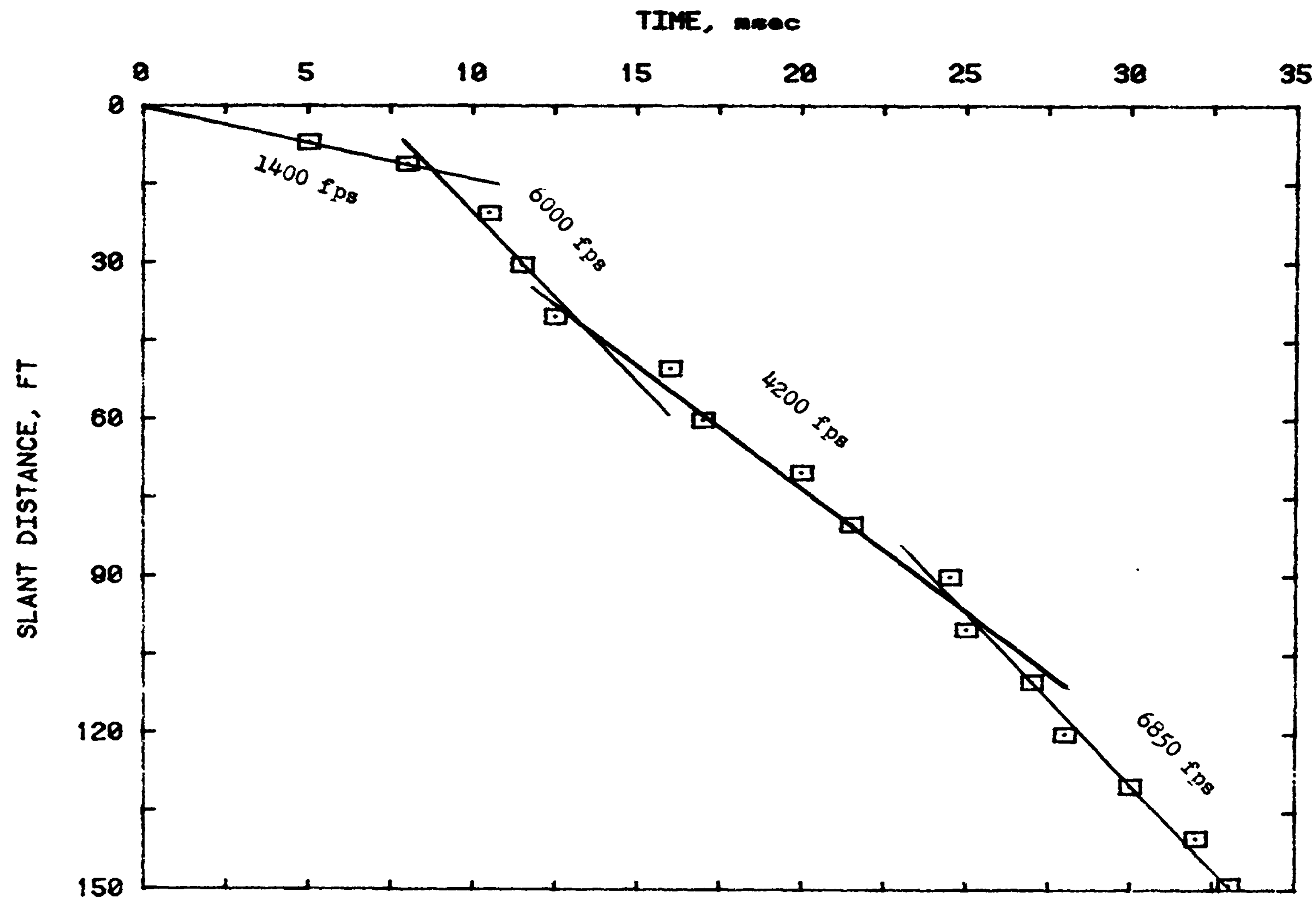


Figure 11. Uphole P-wave test conducted in borehole K

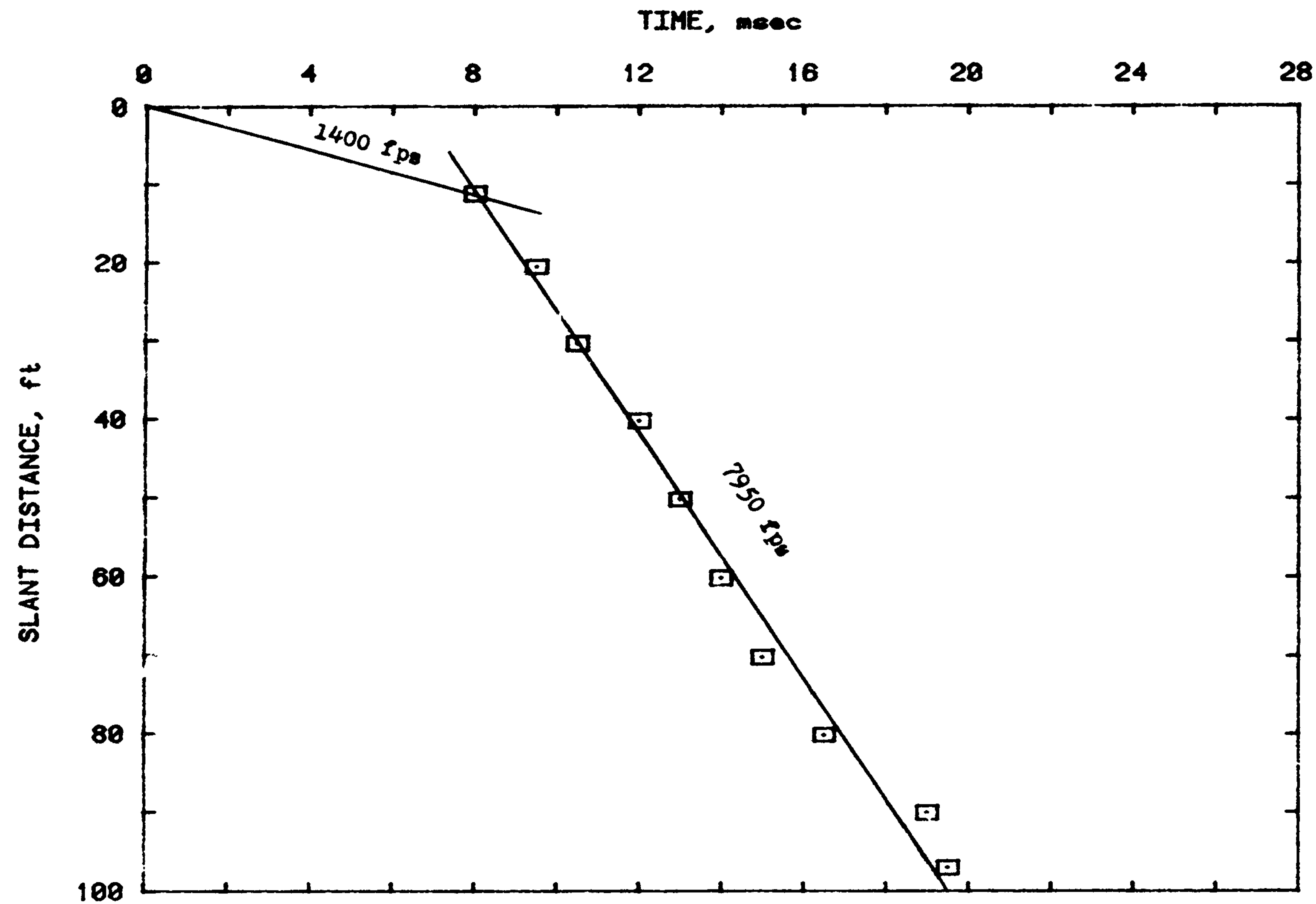


Figure 12. Downhole P-wave test conducted in borehole O

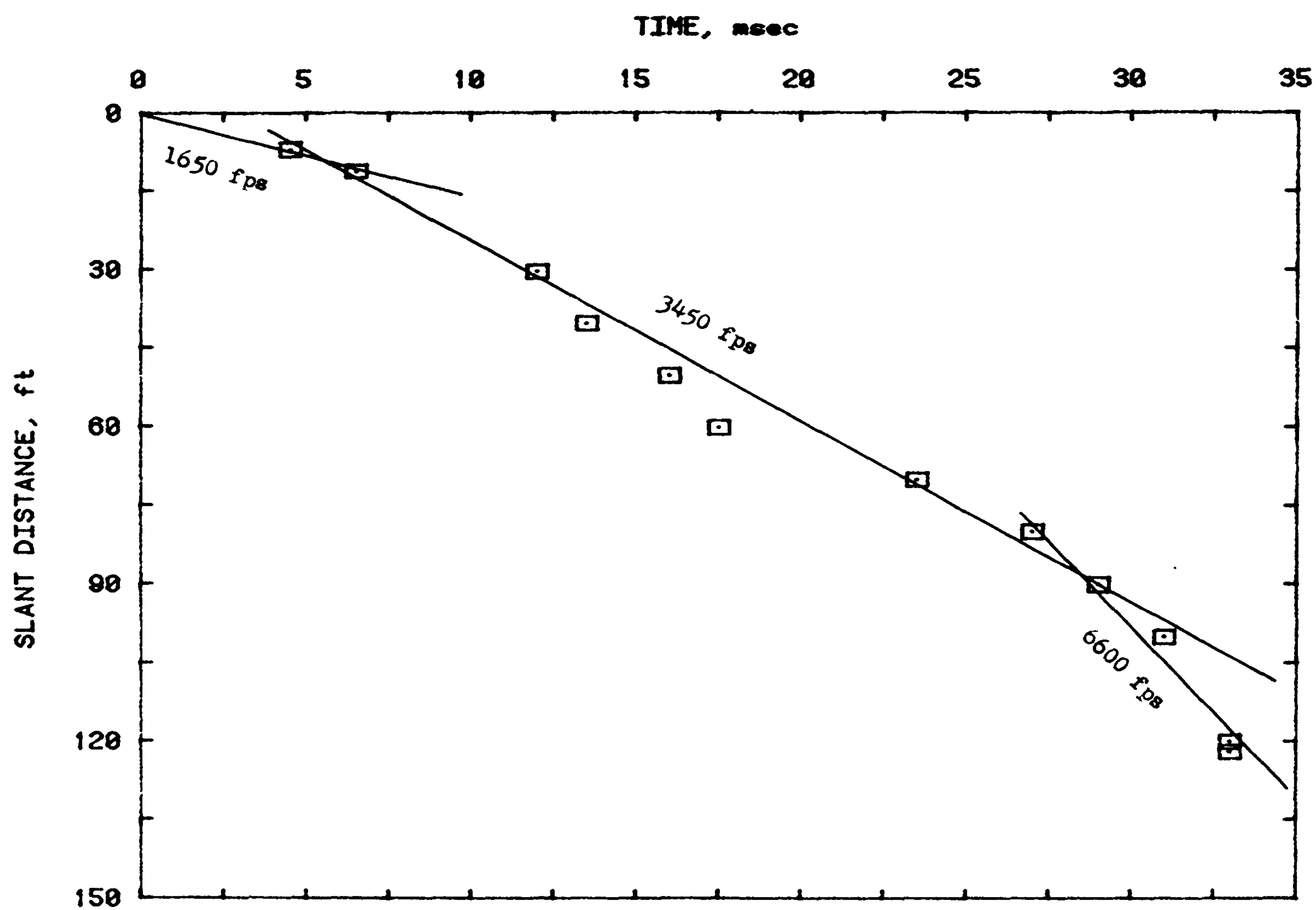


Figure 13. Downhole P-wave test conducted in borehole Q

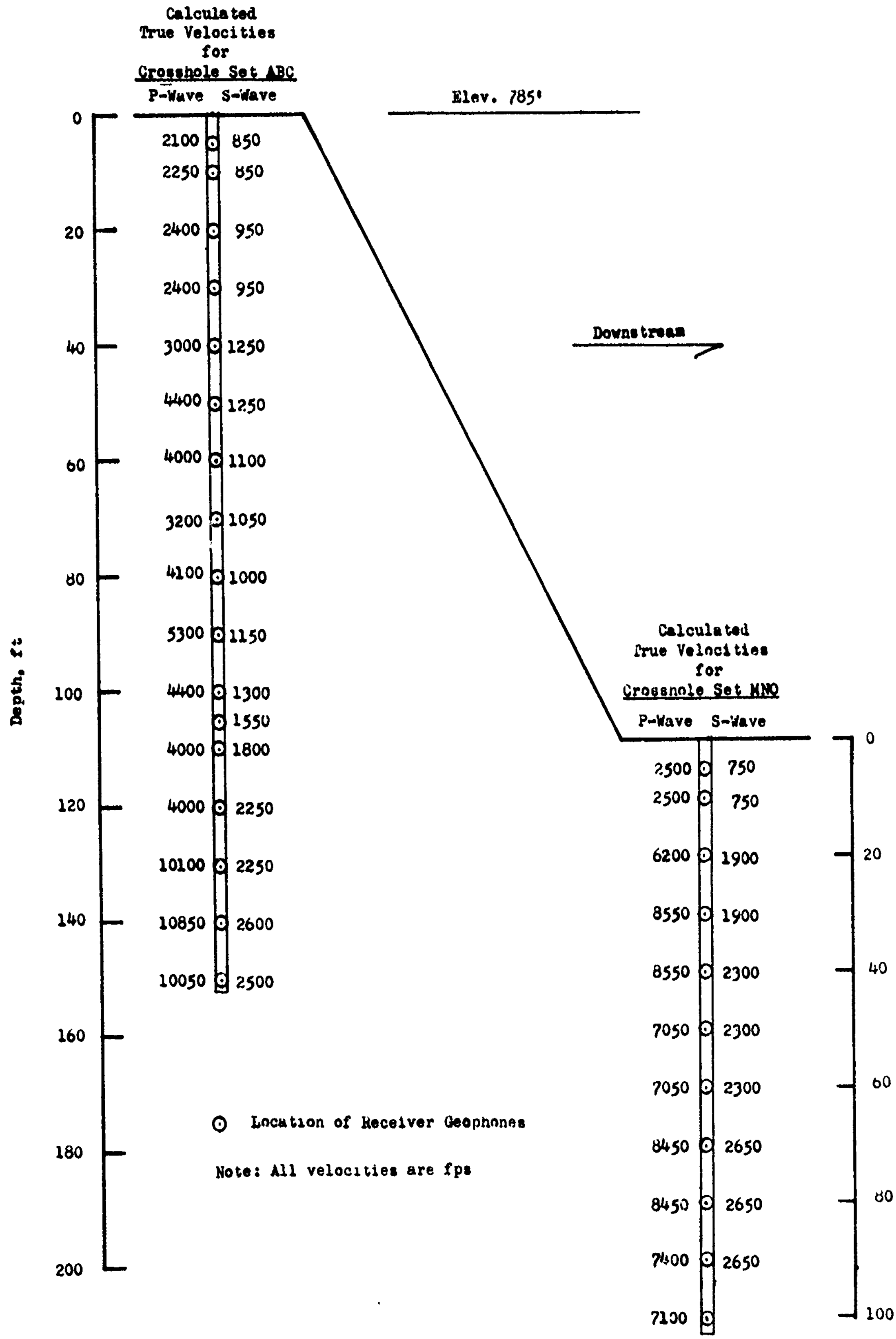


Figure 14. Crosshole test results for cross section through sta 118+00

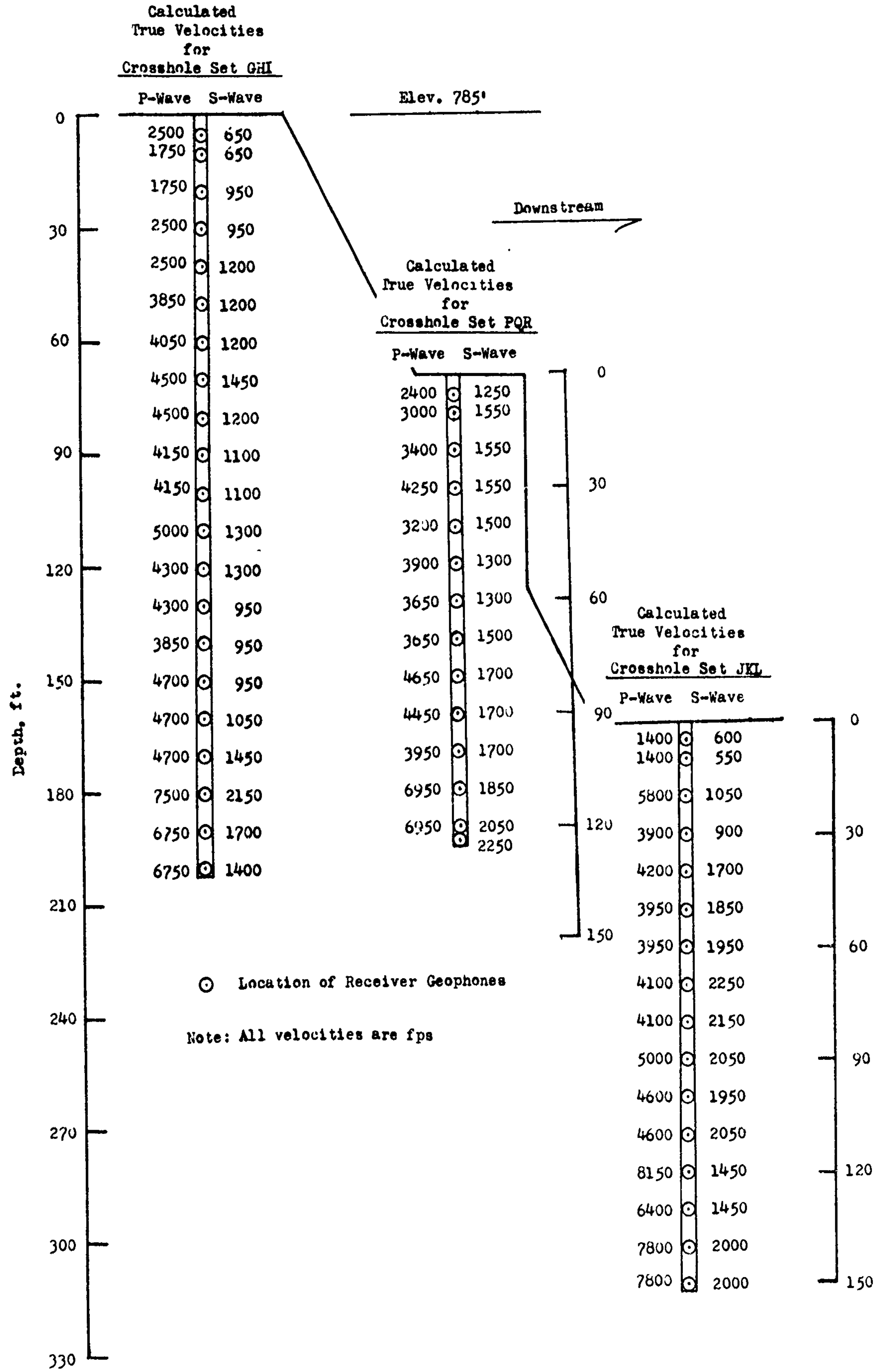
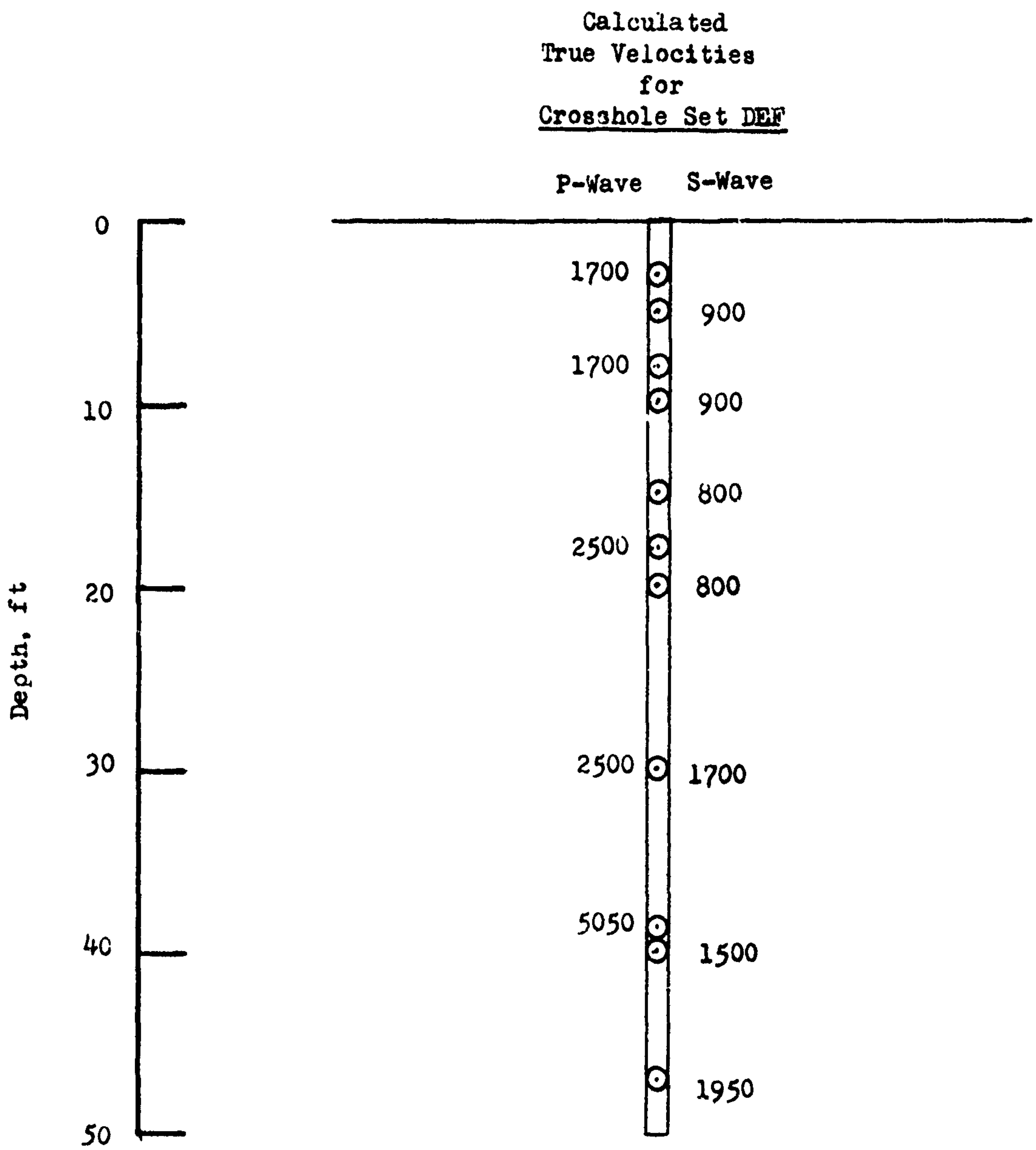


Figure 15. Crosshole test results for cross section through sta 126+00



⊙ Locations of Receiver Geophones

Note: All velocities in fps

Figure 16. Crosshole test results for right abutment

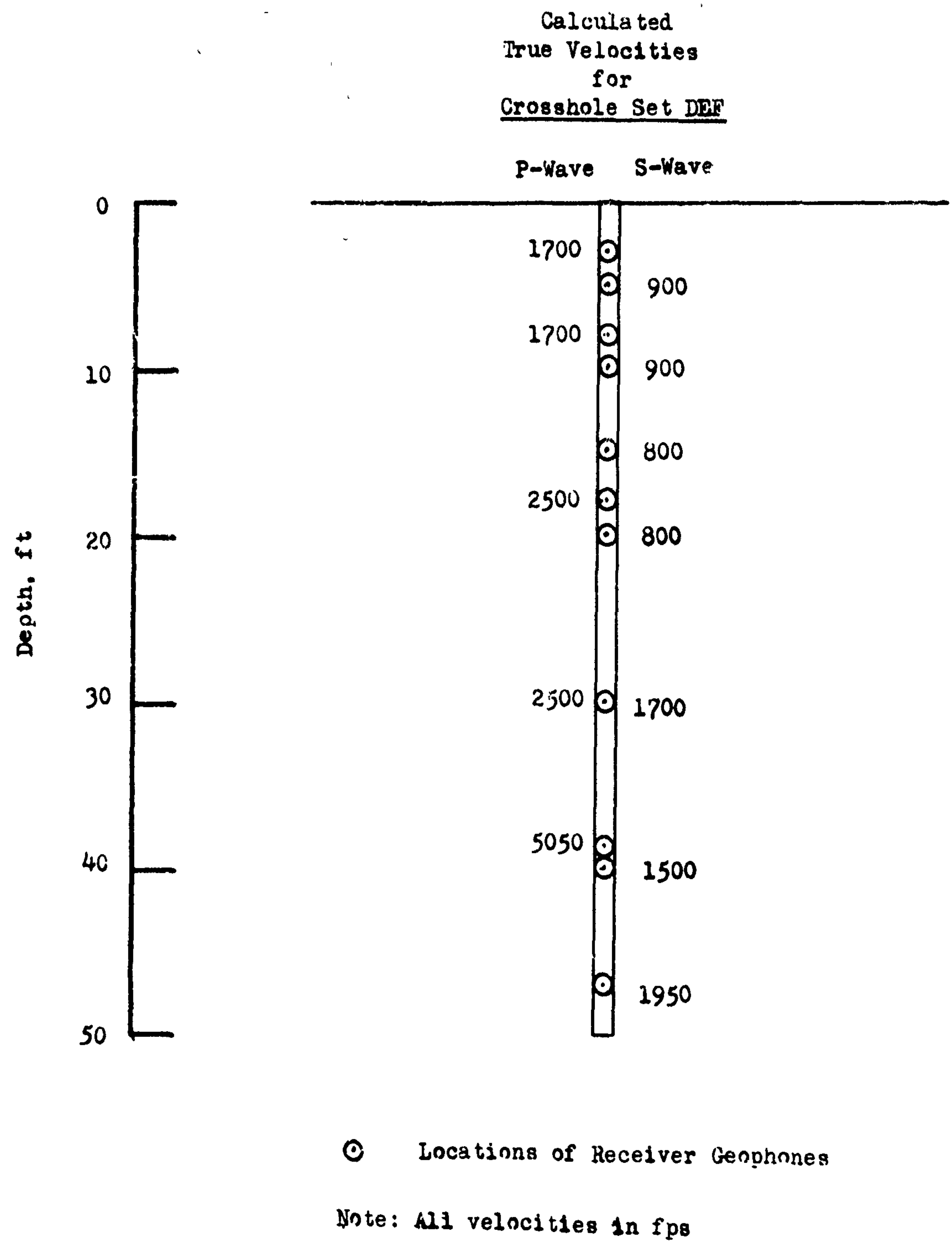


Figure 16. Crosshole test results for right abutment

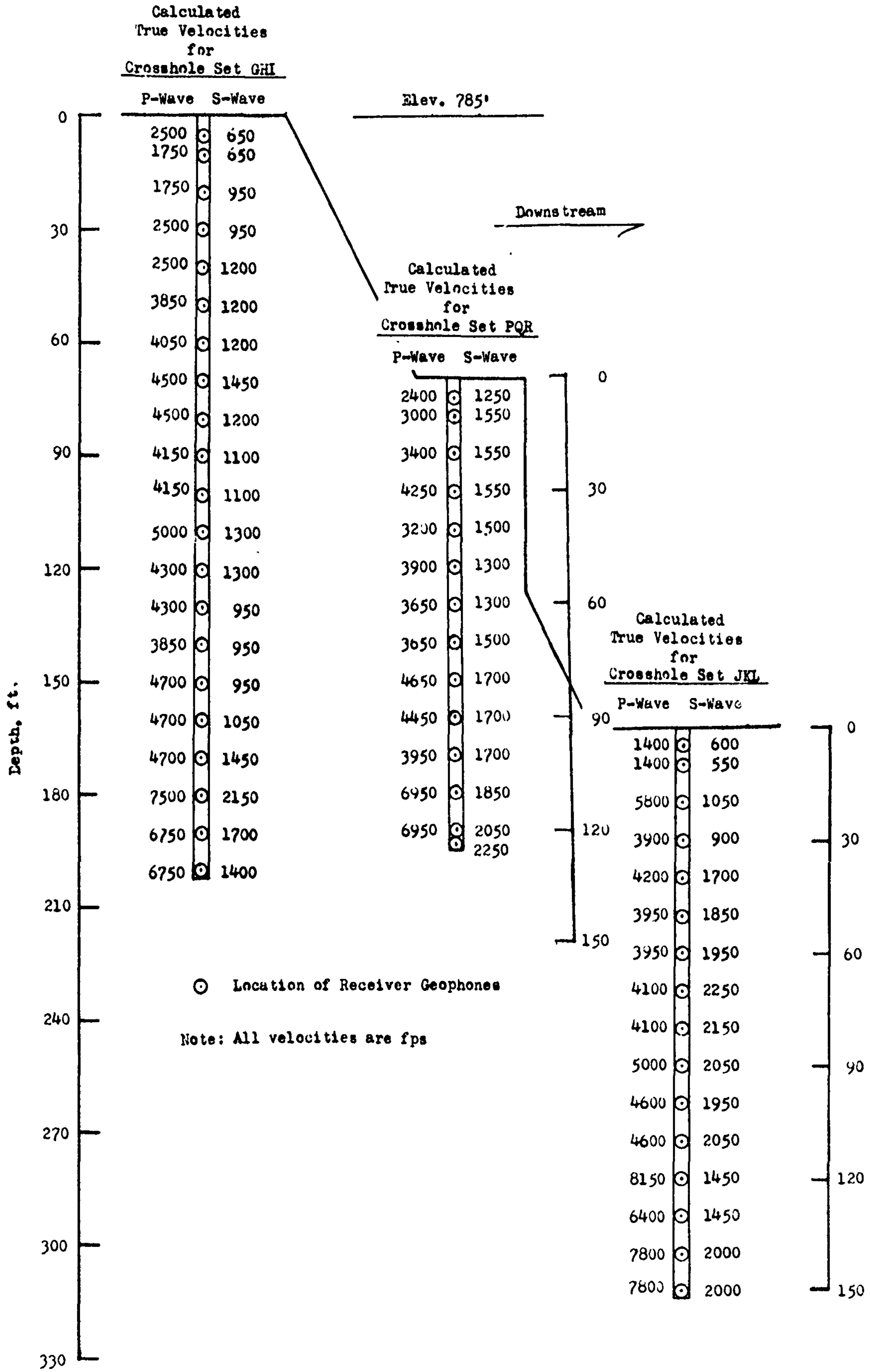


Figure 15. Crosshole test results for cross section through sta 126+00

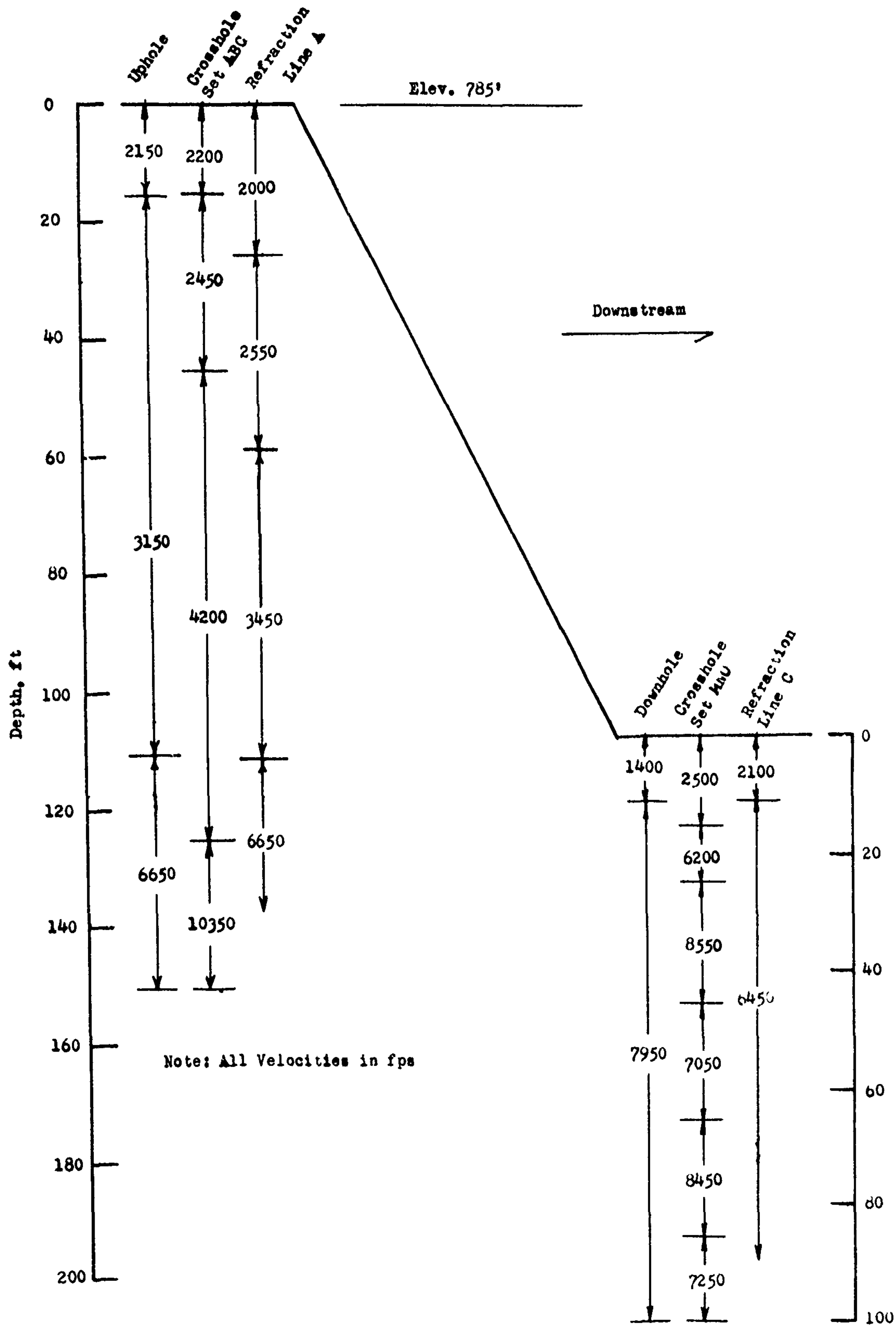


Figure 17. P-wave composite for cross section through sta 118+00

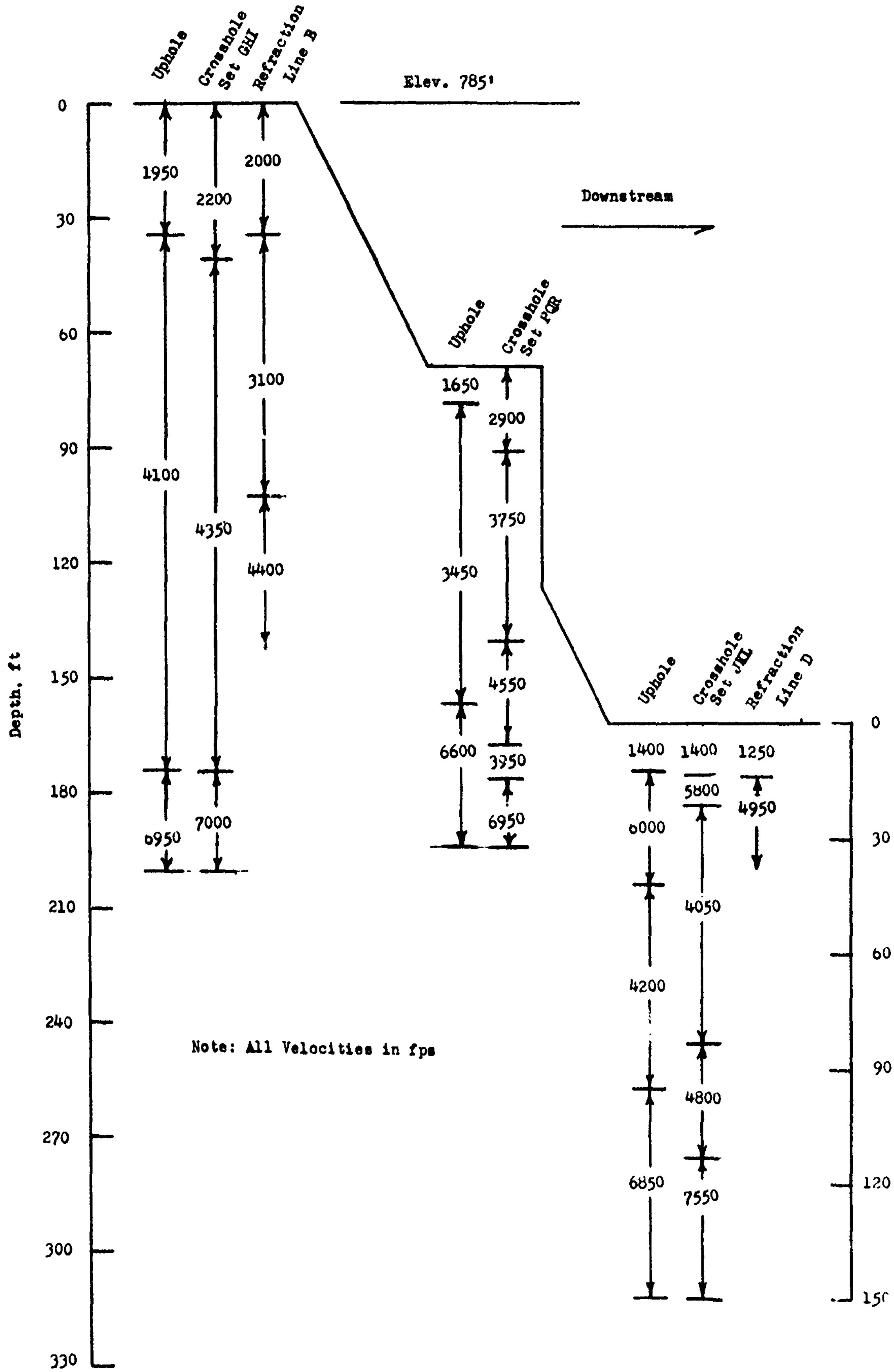
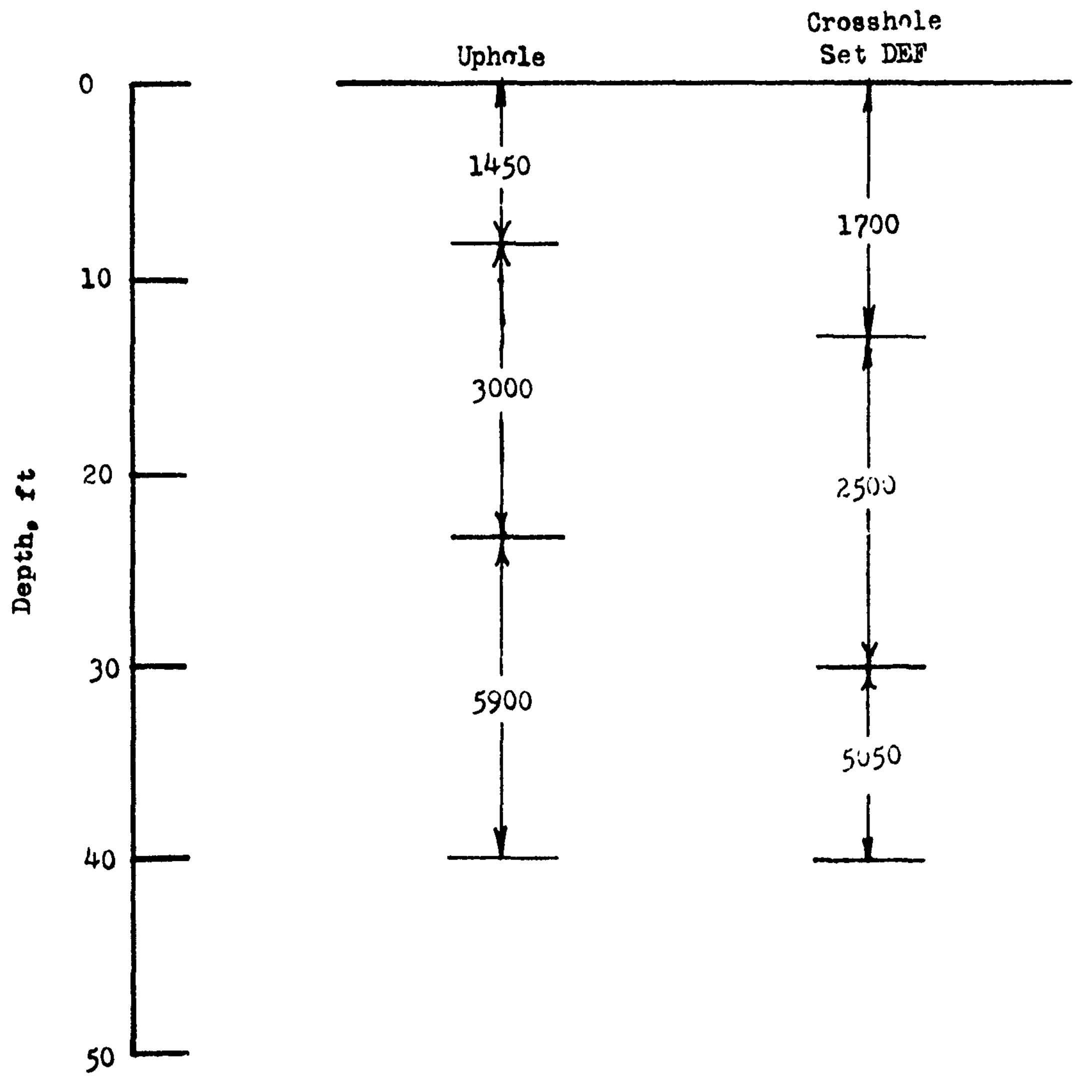


Figure 18. P-wave composite for cross section through sta 126+00



Note: All Velocities in fps

Figure 19. P-wave composite for left abutment

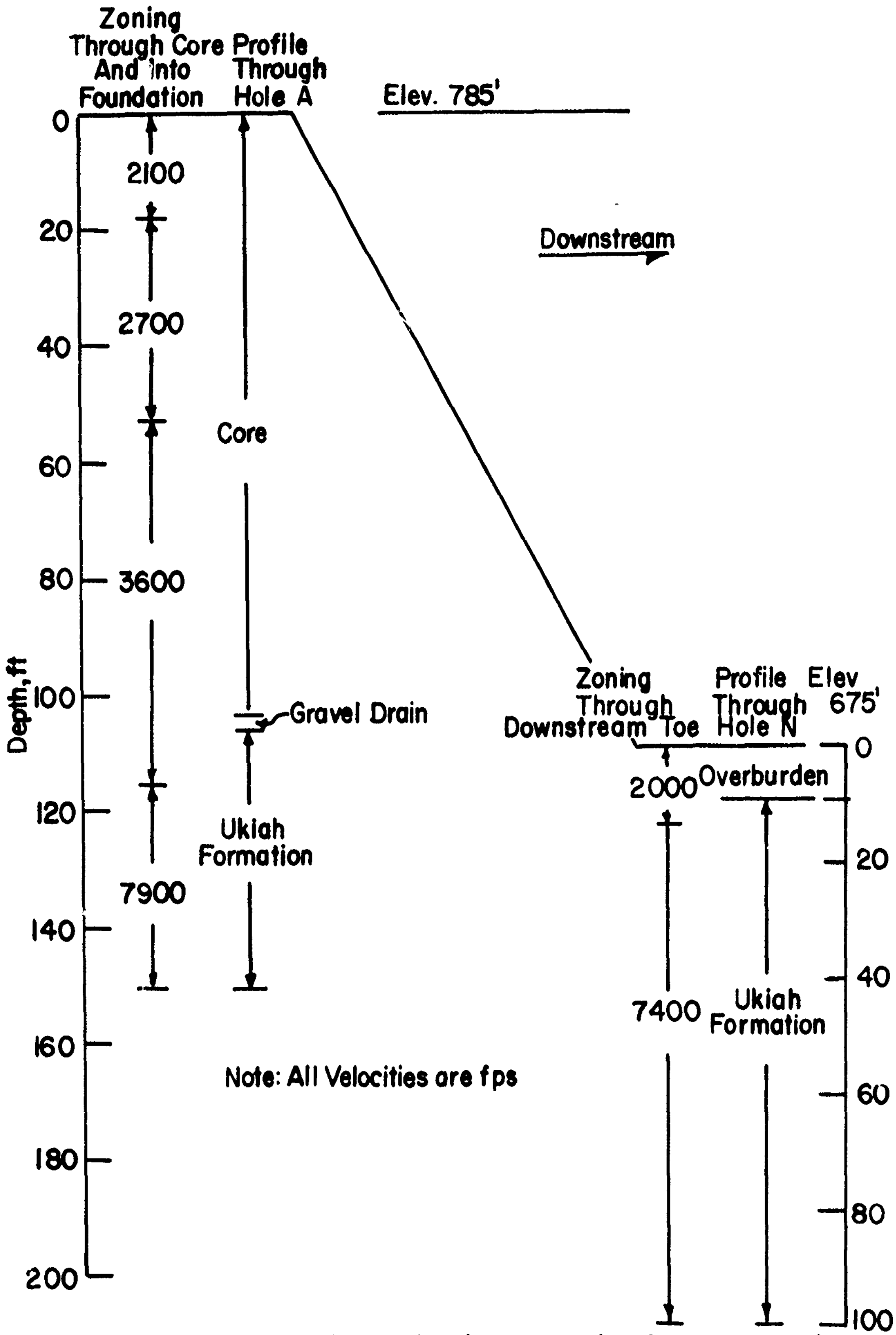


Figure 20. P-wave zonal velocity interpretation for cross section through sta 118+00

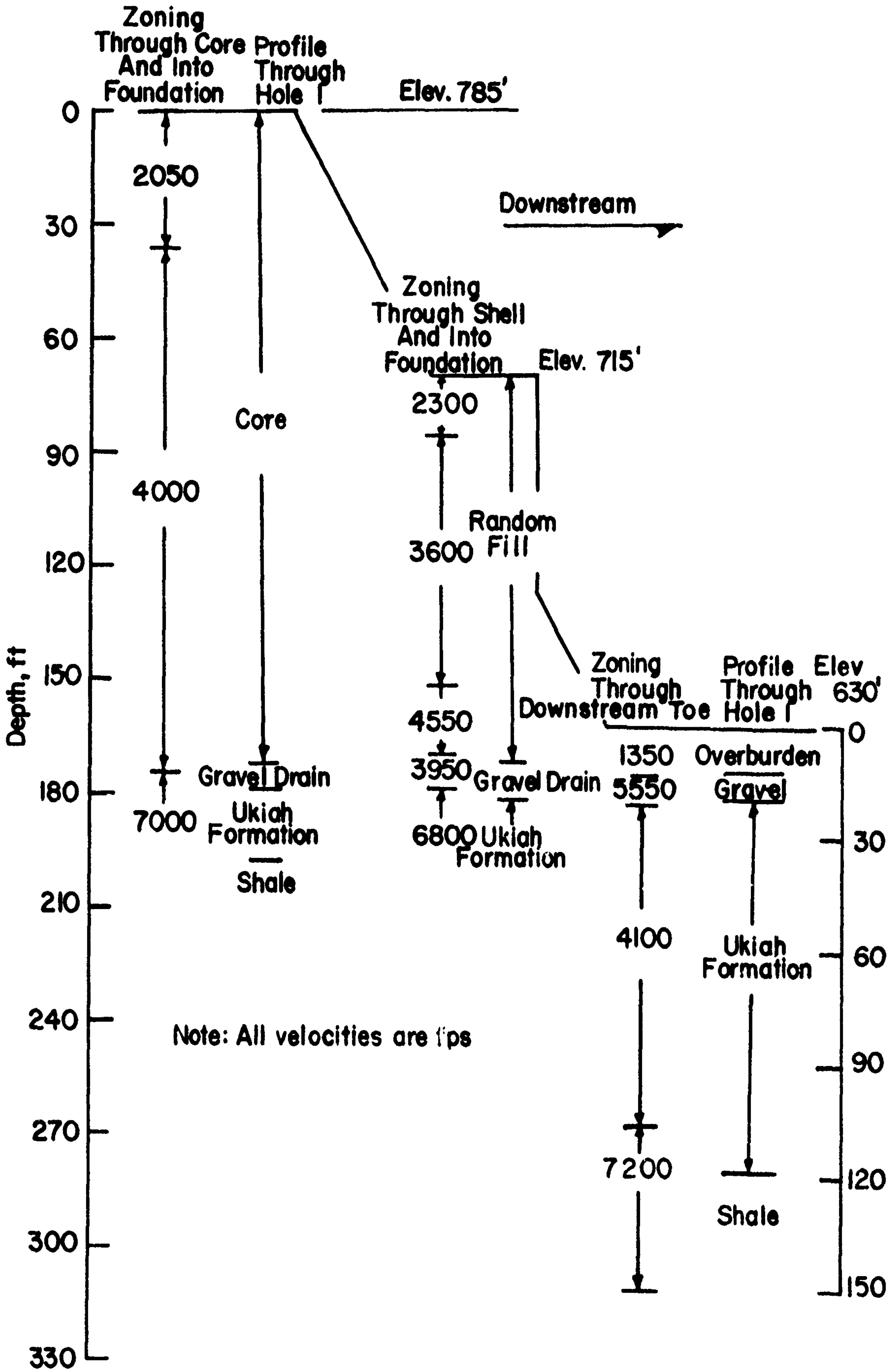
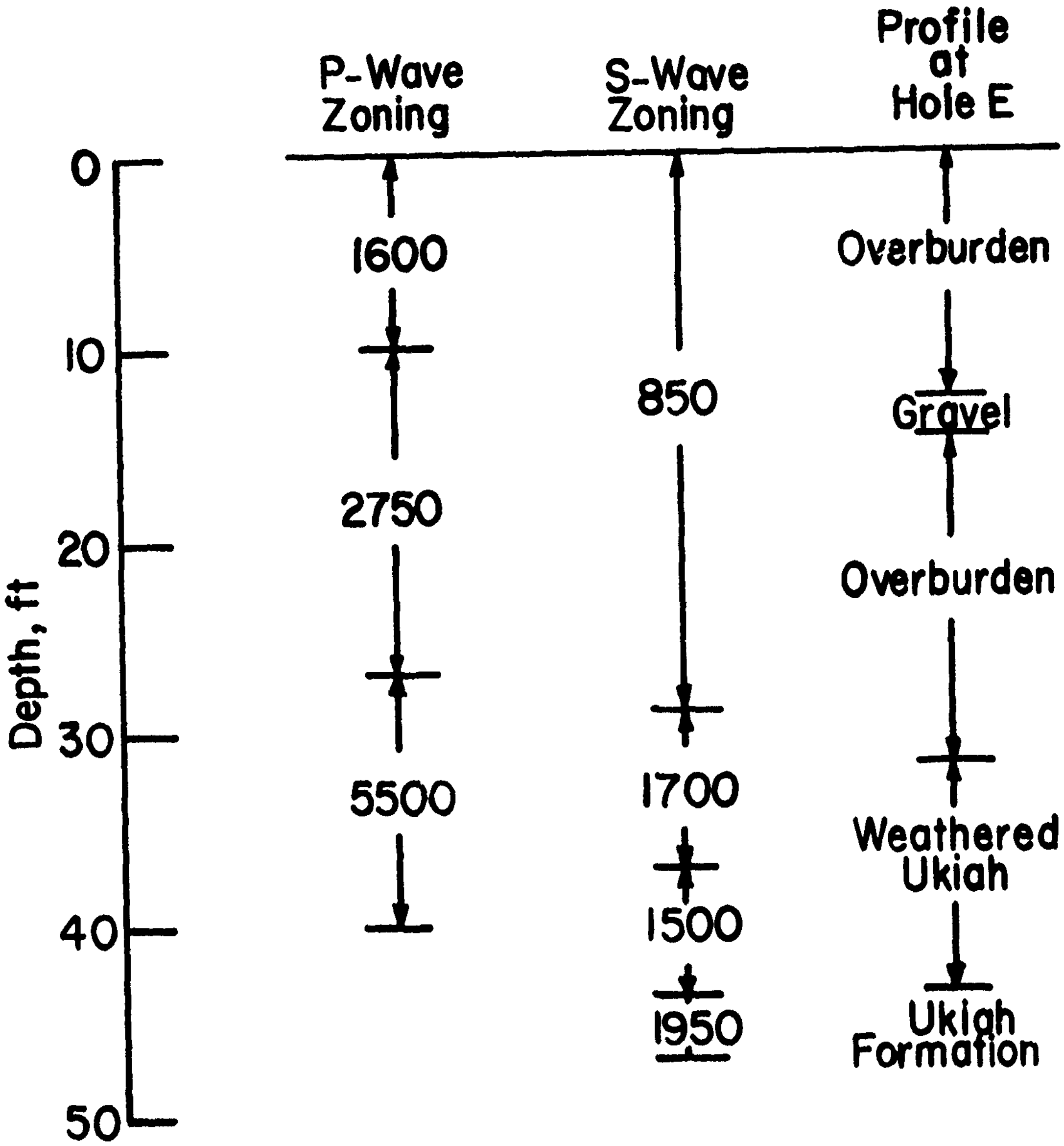


Figure 21. P-wave zonal velocity interpretation for cross section through sta 126+00



Note: All velocities in fps

Figure 22. P- and S-wave zonal velocity interpretations for left abutment

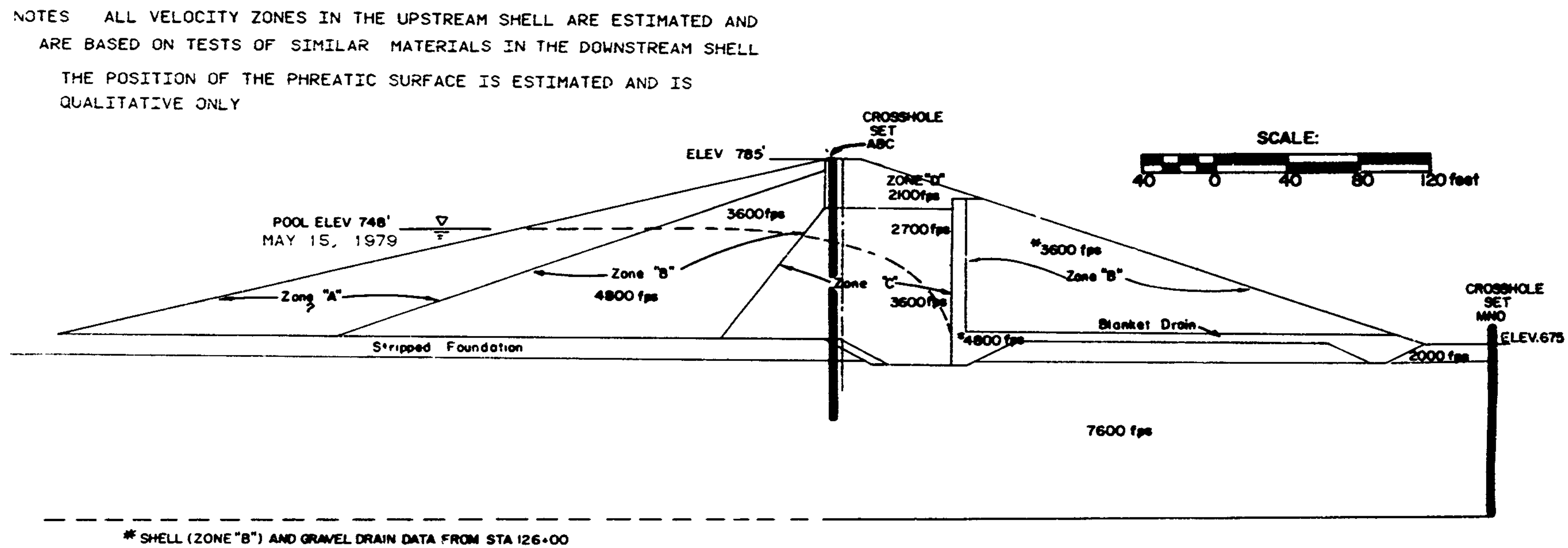


Figure 23. P-wave velocity contours for cross section through sta 118+00

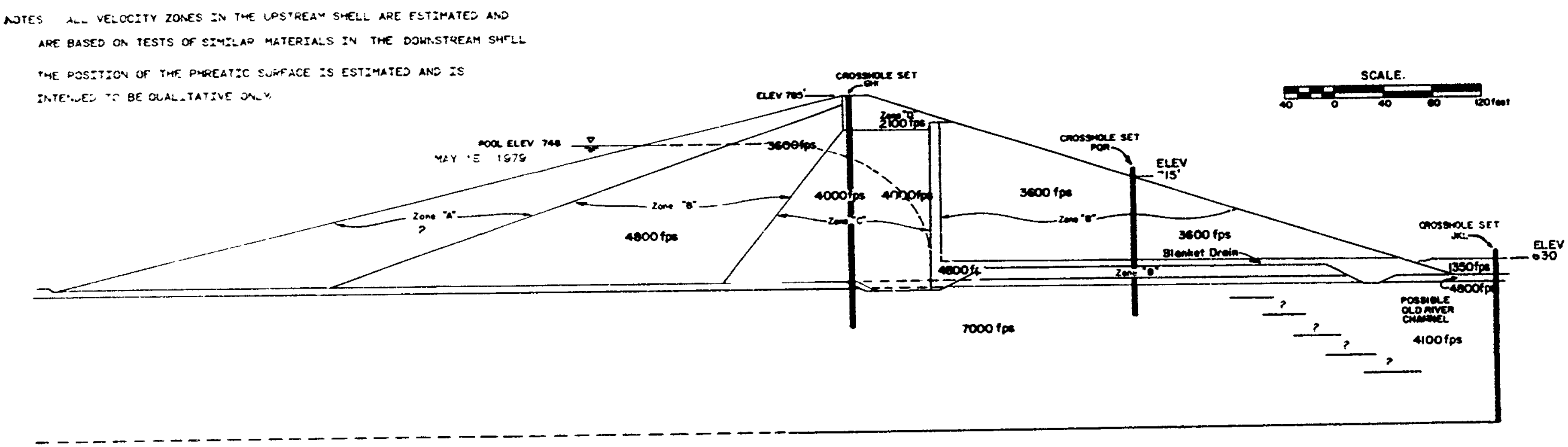


Figure 24. P-wave velocity contours for cross section through sta 126+00

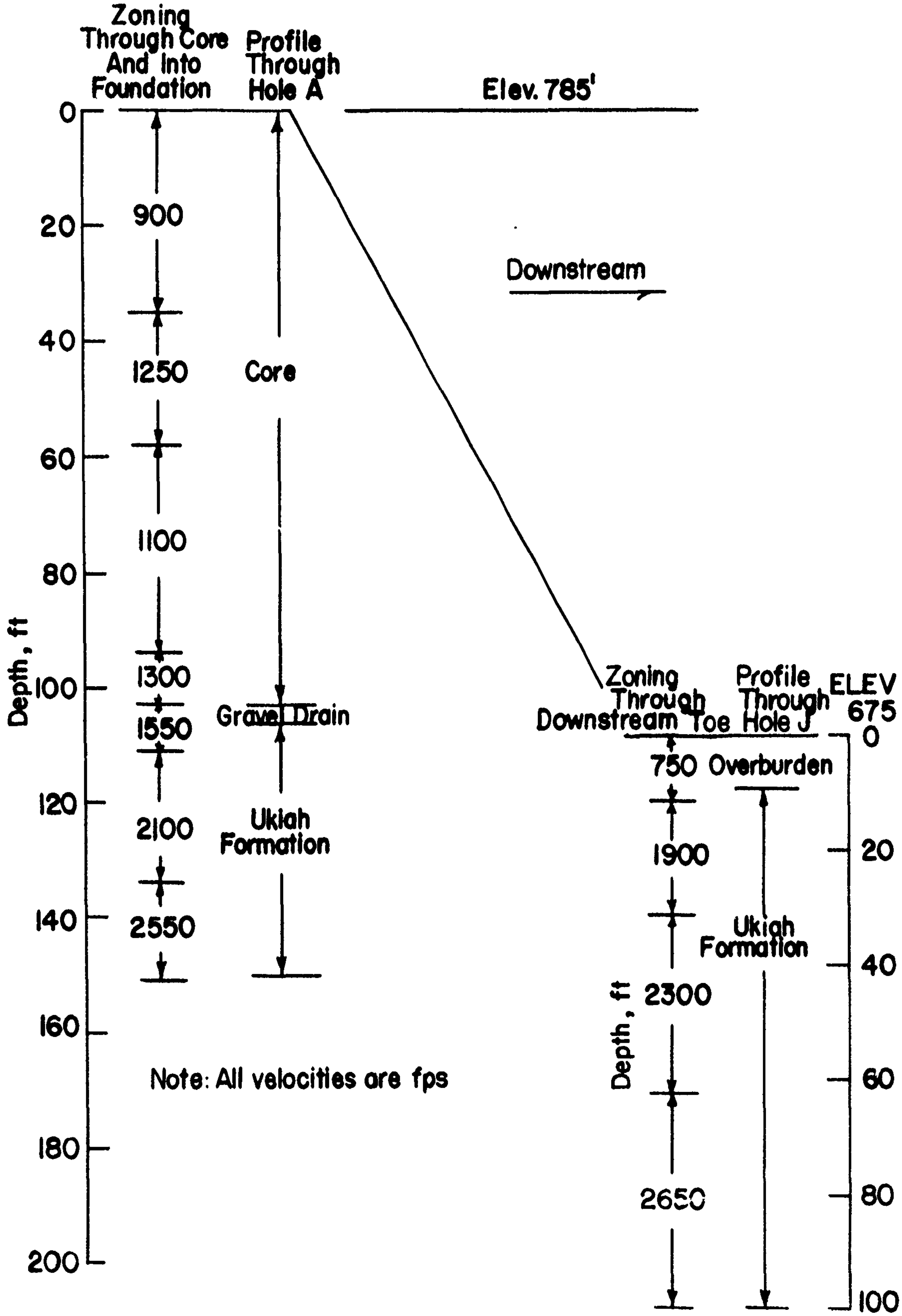


Figure 25. S-wave zonal velocity interpretation for cross section through sta 118+00

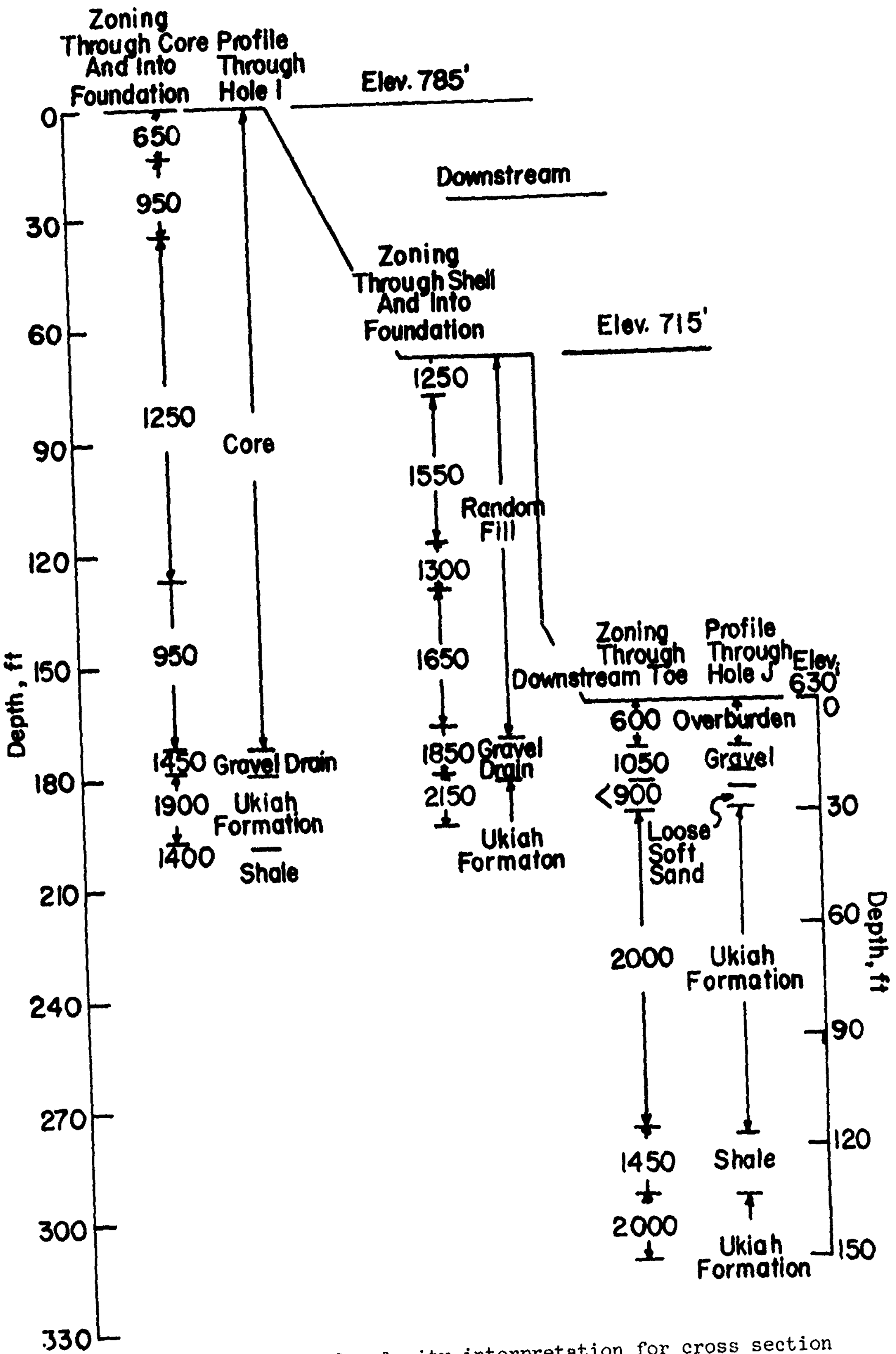


Figure 26. S-wave zonal velocity interpretation for cross section through sta 126+00

NOTES ALL VELOCITY ZONES IN THE UPSTREAM SHELL ARE ESTIMATED AND ARE BASED ON TESTS OF SIMILAR MATERIALS IN THE DOWNSTREAM SHELL

THE POSITION OF THE PHREATIC SURFACE IS ESTIMATED AND IS INTENDED TO BE QUALITATIVE ONLY

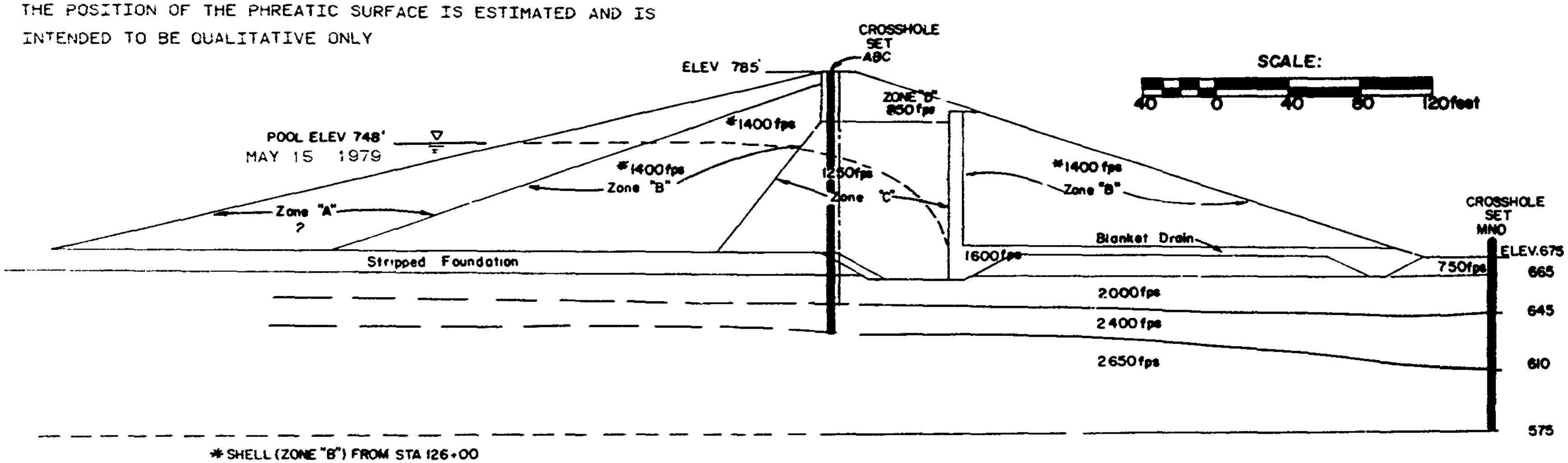


Figure 27. S-wave velocity contour for cross section through sta 118+00

NOTES ALL VELOCITY ZONES IN THE UPSTREAM SHELL ARE ESTIMATED AND ARE BASED ON TESTS OF SIMILAR MATERIALS IN THE DOWNSTREAM SHELL

THE POSITION OF THE PHREATIC SURFACE IS ESTIMATED AND IS INTENDED TO BE QUALITATIVE ONLY

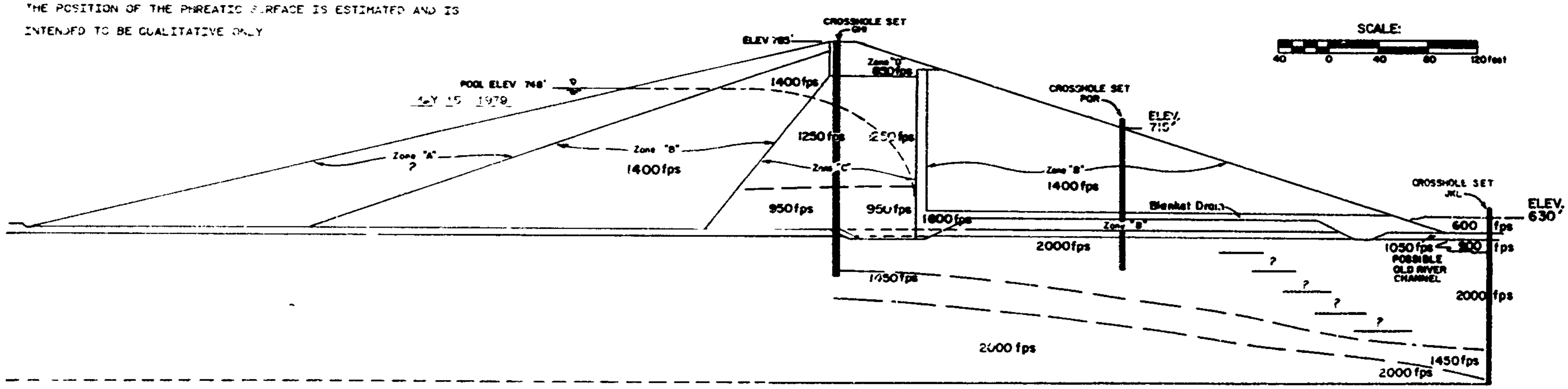


Figure 28. S-wave velocity contour for cross section through sta 126+00

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Wahl, Ronald E
In situ seismic investigation of Coyote Dam : final report / by Ronald E. Wahl, Jose L. Llopis, Robert F. Ballard, Jr. (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station) ; prepared for U.S. Army Engineer District, San Francisco. -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1981.
20, [28] p. : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; GL-81-1)
Cover title.
"March 1981."
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1. Coyote Dam. 2. Elastic waves. 3. Seismological research. 4. Seismology. I. Llopis, Jose L. II. Ballard, Robert F. III. United States. Army. Corps of Engineers. San Francisco District. IV. United States. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. V. Title VI. Series: Miscellaneous paper (United States. Army Engineer Waterways Experiment Station) ; GL-81-1.
TA7.W34m no.GL-81-1